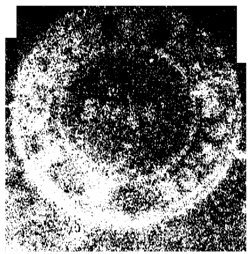

THE STR[illegible]

THE COTTON FIB[illegible]

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TORONTO

THE STRUCTURE

OF

THE COTTON FIBRE

IN ITS RELATION TO TECHNICAL APPLICATIONS

BY

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WITH NUMEROUS COLOURED AND OTHER ILLUSTRATIONS

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1908

ILLUSTRATIONS

PREFACE

In the spring of 1880, when technical education was beginning seriously to occupy attention in this country, I was requested by the Council of the Bradford Technical College, then recently founded, to deliver a series of lectures on the "Structure of the Cotton Fibre in its relation to Technical Applications," and these were given in the large lecture theatre of the Bradford Mechanics' Institute, as the buildings of the Technical College were not completed. These lectures were printed in a volume issued by myself in 1881, and followed by a second edition in 1882.

In 1884 I delivered a similar course of lectures on the "Structure of the Wool Fibre in its relation to Technical Applications," which were delivered in Bradford, Huddersfield, and afterwards in a *résumé* at Nottingham University College, and published in the spring of 1885. Both these books had a large sale, and were accepted as the standard works on the subject, alike in this country, America, and on the Continent. They were, I believe, with the exception of a few detached papers published in scientific journals, the first serious attempt to place our knowledge of these fibres upon a thoroughly scientific basis.

When, in 1886, I was selected by the Royal Commission of the Indian and Colonial Exhibition to report on the wools there exhibited, I had the opportunity of examining probably the finest collection of wools which had up to that time been gathered together, and made extensive notes for future reference.

The books above named have long been out of print, and although many works have since appeared dealing with the same subject, my work and results have been largely embodied in them all, either acknowledged or unacknowledged, and the sketches of the fibres which I made have been universally accepted as authoritative.

I have had many requests, and especially within the last twelve months, to revise them and bring them up to date. Fortunately, during the time since they were published I have made a large number of experiments and observations and sketches, and when the present publishers accepted my offer to write for them a monograph on the subject, to be included in this series of their technological handbooks, I felt the opportunity was not to be neglected. The present volume will, therefore, form the first of three books on "the cotton, wool, silk, and other allied fibres in their relation to technical applications," which will follow in succession as early as possible.

These works will, so far as I can make them, cover the whole ground, and in relation to the cotton fibre it may also be stated that the researches which have been made into the relations and changes of cellulose, which forms its basis, have greatly widened the scope of the

inquiry, and now very important and increasing industries have been founded upon them.

The opinions which I formed in 1880, and which were embodied in my books, have remained unchanged, except in regard to the exact method of development of the cotton fibre in its early state, as being multi-cellular rather than uni-cellular; but all my recent researches, which were made and repeated shortly after the issue of my book, have confirmed the opinion that the fibre is a continuous growth of one cell. With this exception I have been able to draw largely on the materials which I had then collected, and the sketches made at that time of the organs and sections of the cotton flower and pod or boll are practically the same as those recently obtained by photographic means. I hesitated for some time before deciding whether the illustrations should be photographic or graphic, but decided in favour of the latter, as the typical distinctions which I wish to emphasise are only to be found in single fibres which are mixed in the lint with thousands of others, and which photography cannot select or show to the same advantage, although clearly perceptible to the eye, and which distinctions are best represented diagrammatically for educational purposes, just as a painted portrait can be made more characteristic than the most artistic photograph, as the individuality can be better brought out.

The scope of the work is the fibre itself, and its relation to the various processes of manufacture, both mechanical and chemical, rather than the methods employed in

manufacture, my object being to summarise the distinctive character of the raw material, upon the nature of which all the changes in the process of manufacture must be based if the best results are to be obtained. Hence I deal not with the machinery but with the raw material which it treats, and have to assist me in this inquiry an extensive knowledge of the machinery used, as having been practically engaged, on a large scale, in both the cotton and worsted spinning industries. Thus, when looking at the fibre from the mechanical side of the question, I examine it as I should any other structural material, from an engineering standpoint, so as to determine what its different qualities are, and how they may be best utilised in connection with any method of manufacture, so as to enable those who wish to manipulate it to avoid such errors as in structural iron-work would be made if cast-iron was to be employed to resist tension and wrought-iron compression. So also, when dealing with the question of dyeing, my inquiry was confined to the method in which the fibre lends itself to the reception of the dye and the way in which the dye-stuff is received by the fibre, rather than the methods employed to dye it, although the limitations of these methods are always taken into consideration. I have endeavoured also to embody, so far as I was able, the researches of others in the same direction as my own, and have, wherever I could trace these sources acknowledged them by reference, and I have to thank several friends for kindly looking over the proofs. I am specially indebted to Professor Knecht, Ph.D., M.Sc., etc.

Professor of Tinctorial Chemistry in the Manchester Technical College; to Prof. Julius Hübner, M.Sc. etc., of the same college, and to Mr. James M'P. Miller, B.Sc., in reference to reading the proofs of the last three chapters; and to Mr. Jowett, of Messrs. Cook and Co. of Manchester, who made the single-yarn tests for me on the Moscrop automatic machine; also to Mr. J. H. Lester, M.Sc., F.I.C., of the Manchester Chamber of Commerce testing-house, for information supplied, and to Messrs. James Dilworth and Son of Manchester, and Mr. A. Hoegger, Chairman of the British Cotton and Wool Dyers' Association, Ltd., who supplied me with complete ranges of samples of grey and dyed yarns. I have also to thank the publishers, printers, and artists, who have combined to make the work a success, and especially in the faithful reproductions of my drawings; which will render it additionally interesting to the readers.

I give a list on page xx of the various works which I have consulted during the last few years, and am specially indebted to the classical researches on cellulose made by Messrs. Cross and Bevan, and embodied in the books which they have issued from time to time.

Although this work does not profess to be exhaustive it is, nevertheless, so far as I can make it, a *résumé* of our knowledge on the subject up to the present day, and I hope its perusal may stimulate further research in those directions in which our information is yet incomplete. With this wish I send it forth as my contribution to the materials which must form the base of a higher techno-

logical knowledge, upon which the commercial prosperity of the British people must in the future depend, and subscribe myself

F. H. BOWMAN.

MANCHESTER, *March* 1908

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LIST OF BOOKS CONSULTED BY THE AUTHOR

Botany, Text-Book of. Strasburger. Macmillan, London. 1903.

Calico Printing, Bleaching, and Dyeing. C. O'Neil.

Cellulose and Cellulose Products. Joseph Bersch. Kegan Paul. London, 1904.

Cellulose and Various Supplements. Cross and Bevan. Longmans, London, 1903.

Chemistry and Physics of Dyeing. W P. Dreaper. Churchill, London, 1906.

Chemistry and Practice of Finishing. Percy Bean. Kirkham and Pratt, Manchester, 1905.

Chemistry. Thomson and Bloxam. Churchill. London, 1903.

Chemistry, Organic. Perkin and Kipping. Chambers, Edinburgh, 1907.

Cotton. C. P. Brooks. Spon, London, 1898.

Cotton Fibre, Structure of. F. H. Bowman. Palmer and Howe, Manchester, 1882.

Cotton Fibre, Structure of. Hugh Morrie. Heywood, Manchester, 1890.

Cotton from Field to Factory. J. Mortimer. Palmer and Howe, Manchester, 1894.

Cotton Plant. A. Flatters. Sherratt and Hughes, Manchester, 1906.

Cotton Plant U.S.A. Department of Agriculture. Washington, 1896.

Cotton Trade. Schulz-Gaevernity. Marsden, Manchester, 1895.

Cotton Spinning. R. Marsden. Marsden, Manchester, 1886.

Cotton Spinning. W. S. Taggart. Macmillan, London, 1907.

Dyeing, Manual of. Knecht, Rawson, and Loewenthall. Palmer and Howe, Manchester, 1893.

Dyeing of Textile Fabrics. J. J. Hummel. Cassell, London, 1885.

Humidity in Cotton Spinning. Sir B. Dobson. Heywood, Manchester, 1897.

Journal of the Society of Chemical Industry.

Journal of the Society of Dyers and Colourists.

Technology of Textile Fibres. Georgievics. Scott, London, 1902.

Testing House, Laboratory Notes. J. H. Lester. Blacklock, Manchester, 1903.

Textile Fibres. J. M. Matthews. Chapman and Hall, London, 1907.

Textile Raw Materials. J. Zipser. Scott, London, 1901.

Various Current Technical Journals.

Wool Fibre, Structure of. F. H. Bowman. Palmer and Howe, Manchester, 1885.

CHAPTER I

PRELIMINARY

Introduction.—The rapid advance which has been made in scientific research during the last half-century has rendered it possible for those who are engaged in industrial processes to turn these investigations to the highest possible use.

Almost every department of human knowledge has its technical applications; and those who are engaged in the various arts and manufactures will surpass their fellows, not only in this country but in international competition, in proportion as they possess the knowledge and capacity to turn these purely scientific researches to the best technical application. Until a comparatively recent period it was considered that, those departments excepted where the processes were of a chemical nature, there was very little room in the manufacture of textile fabrics for the exercise and employment of purely scientific knowledge, and that those rules and the craft of hand, which were the outcome of practical experience, and which are known as "rules of thumb," were amply sufficient to secure the highest attainable state of perfection.

The advance of technical education in Great Britain, the Continent, and America has, however, shown that there is

no department of Industrial Art where there is a wider scope for the exercise of the highest scientific knowledge than in the textile manufactures, not only on account of the very varied nature of the raw materials used, but also on account of the great variety of processes to which the materials are subjected, and which processes depend upon almost every department of scientific knowledge for their successful operation.

At the foundation of all successful manufacture there must be a thorough knowledge of the nature of the raw materials to be operated upon.

This knowledge must extend both to the mechanical and chemical nature of the raw material, because upon their mechanical structure depends the character and class of machinery which can be used in the manufacturing process. Thus the machinery and processes employed to treat cotton must, because of the great difference in the two staples, differ both in design and method of operation from those used for manufacturing woollen goods. It matters little, however, whether the processes are mechanical or chemical; for it stands to reason that where the raw material is co-ordinated to the use to which it is to be applied in all its relations, and the processes to which it is subjected are correspondingly co-ordinated to the nature of the materials used, that there is a far better chance of the highest effects being attained than when the material is selected at random and the processes undirected by a knowledge which is more than superficial. In the early days of manufacturing, when most of the processes were performed by manual labour only, and such chemical changes as were necessary were performed upon small quantities at a time, as in the pot-dying of yarn, there was, necessarily, a greater opportunity for the careful selection of the raw material

than is possible to-day where household manufacture is superseded by the factory system and manual labour by self-acting machinery. Time was also of less value in these primitive days, as well as labour being cheaper, and thus many defects were avoided, by extra care and attention, than is possible now where the processes are carried out on so much larger a scale and with far greater rapidity.

Where "rule of thumb" was employed it also frequently happened that processes were carried on without any consideration of the succeeding ones, and thus positive injury was often done in the earlier stages of manufacture which could not be repaired in succeeding stages. It is a fundamental principle in all manufactures that the greatest perfection in the result can only be attained by the perfection of each process in the successive stages through which the raw material passes, and this can only be accomplished by a careful and scientific adaptation of means to an end, and in intelligent forethought which sees the end from the beginning, and which thus provides for all contingencies, and secures that the best results are attained at the least cost.

All the materials used in textile manufacture, from whatever source they are derived, consist essentially of a series of long filaments, either single or double or in bundles and varying in length, diameter, and strength; and the object of their treatment which constitutes the first process in textile manufacture is so to arrange these filaments or fibres that they constitute a continuous thread or strand, in which the fibres are more or less parallel to each other, and are retained in position and prevented from drawing out by being permitted to irregularly overlap each other, and by being twisted together round a central axial line into a more or less even cylinder of sufficient strength to

enable it to be knitted or woven into a reticulated or plain solid web of any convenient length and width, and forming what is called a piece of cloth.

Some of these fibres, such as cotton, wool, or silk, which fortunately comprise those most in use, are obtained from their source in a state in which they need no preparatory process to render them fibrous; but those in another class, including all the bast fibres, which are enclosed within the substance of the plant and cannot be obtained by simply plucking, or shearing, or unwinding, but require a somewhat complicated series of chemical and mechanical processes, which if not properly performed or misunderstood or misconducted, will greatly detract from the value of the fibre, by entirely changing its character and destroying its most useful properties through the injury which is done as the result of ignorance.

These preliminary processes are as essential as the actual manufacturing process itself, and require the utmost care and attention if the subsequent raw material is to be of the highest class of its respective kind. So, too, the suitability of any fibrous material, when it is obtained, for any specific purpose, depends largely on its mechanical construction and properties. Thus those fibres, which have a more or less tubular construction and are strengthened so as to prevent deformation of the tube when subjected to flexure, by means of nodes or rings, are obviously less suitable for yarn or fabrics which have to be subjected to constant acute creasing, than those where the whole of the fibre is built up of lanceolate cells which yield under pressure and possess a certain resilience, and which will not, therefore, take a permanent set or rupture and thus escape mechanical deterioration under the same circumstances.

No treatment which retains the best characteristics of

any raw material can alter its essential natural properties, and the manufacturer can only work with the materials which nature affords, but he can change and alter the machinery to work it. Unfortunately, in the past a very large portion of the machines used in textile factories have been designed by machine-makers who have not had experience in manufacturing, or manufacturers who have had no knowledge of machine-making, or by both who have not had at command knowledge of the structure and mechanical properties of the raw material to be used.

Even with these disadvantages great progress has been made, and it is the object of this work to throw light on the nature of the various fibres so as to enable the machinery to be adapted to the process in order to avoid unnecessary damage.

It is easy to picture to the mind a theoretically perfect raw material which should possess all the most desirable qualities required for textile purposes in their most perfect form, but no such fibre really exists. Fortunately many of those at the disposal of man possess many of these qualities. The knowledge which science has placed within his reach has enabled him, by attention to the cultivation of the plants and animals from which they are derived, to greatly increase all the desirable properties, and to minimise those which are undesirable. Such advances are easily recognised in the difference between wild cotton and the best cultivated varieties, or in the immense difference in quality between the wool of the wild sheep and that supplied from the highly bred flocks of Europe or Australia.

Nature of Materials.—In textile manufactures the materials employed, from whatever source they are derived, must always possess certain characteristics which may be summarised as follows :—

1. Tensile strength and length of staple or fibre.
2. Uniformity in length and other features.
3. Flexibility and elasticity.
4. Small and even diameter.
5. A surface capable of friction.
6. Porosity and permeability.
7. Resistance to disintegration and decay.
8. Lustre.
9. Abundance in quantity.

A raw material is valuable just in proportion as it contains more or less of these characteristics, and the whole of them are attained in the highest degree in the four great classes of material which form the basis of the cotton, wool, silk, and flax industries.

1. *Tensile Strength.* The essential feature of textile fabrics is that they are composed of threads, either separate or in combination, and woven together so as to give a plain, figured, or reticulated surface; and in order to enable this to be done the fibres of the material of which these threads are composed must have a certain average tensile strength, so as to render the process of making the threads and afterwards weaving them, possible.

The strength of the materials varies very much, but in many cases, after the thread is formed, the strength can be increased by artificial means, such as the use of size and other stiffening materials to bind them together, and which can be removed where necessary when the weaving is completed.

The strength which can be obtained by using any fibre depends on two functions.

(*a*) The inherent strength which the fibre possesses as a result of its origin and structure, and

(*b*) The length of the fibre which enables it, when in

combination with other fibres used in the thread, to be twisted into a strand so as to bind them together, average their strength and enable them as a whole better to resist tensile strain. This length is most important, as in addition to the difficulty of forming a thread from very short fibres, arising from mechanical considerations which limit the use of ordinary spinning machinery, they cannot be twisted together so as to give sufficient hold, without excessive twist, which is apt to cause the thread to curl, and the thread is, therefore, weak as the separate fibres draw out from each other. The same material often exhibits wide variations in this respect, as may be seen in the difference in the length of the filaments of short Indian cotton as compared with the long Sea Island fibre, and in fine Southdown wool as compared with Lincoln or Leicester wool.

2. *Uniformity.*—Another important consideration is uniformity in length of staple, as this greatly facilitates the working of the fibre, as the rollers in drawing out the material during the process of spinning can then have a definite setting, so as exactly to suit the length and prevent the slipping of the fibre from between the rollers, or the breaking by excessive tension.

As no fibres are perfect in this respect, but all vary more or less, selection on the basis of uniformity in length of the same quality is employed as in the grading of cotton or the sorting of wool, and also mechanically attained as in the combing process of either cotton or wool.

3. *Flexibility.*—Whatever is the character of the fibre it is essential that it shall not be brittle, so as to snap or break suddenly when subjected either to longitudinal or torsional stress, but must possess a certain amount of flexibility and elasticity.

Fortunately all the fibres in use, whether they are derived from vegetable or animal sources, possess these characteristics in a high degree, although they all differ widely as a result of their diverse mechanical structure, the modulus of elasticity of a wool or silk fibre being very different from that of cotton or flax.

4. *Evenness.*—The diameter or thickness of the fibre also must be small in relation to its length, or otherwise the difficulty of forming a thread becomes very great, arising partly from the resistance of such a form to torsion in putting in the twist and also in obtaining a sufficient frictional hold of the fibres on each other. Evenness of diameter is also essential, because if the variation is very great it either greatly reduces the average tensile strain which the fibre can sustain without fracture, or else renders difficult the drawing-out process in spinning, and also results in uneven diameter in the whole thread, which presents difficulties in the weaving of the yarn. Where variation in thickness is required for artistic and other purposes it can be best attained by artificial means.

5. *Surface Friction.*—Fibres which possess a perfectly smooth surface, such as thistle-down or vegetable silk, however lustrous and long, cannot be used by themselves in textile manufacture, and are also very difficult to use, even in connection with other fibres, because they cannot hold together, and therefore it is impossible in the drawing-out process to do entirely without twist in those machines which precede the spinning of the thread where the final twist is put in. In most vegetable fibres which are obtained from the Bast or inner layer of the cellular structure of the plant stem, after cleansing of the fibre from the gummy and other resinous and binding material, there is always a certain roughness remaining on

the surface which enables other fibres to catch on to it and retain their hold; and in many of them there is also a jointed structure which is almost characteristic of bast fibres, and which, when twist is put in, prevents the fibres slipping on each other, in the same way as would occur if two knotted cords were twisted together.

In fibres, of which cotton is the most noted example, which are plumose, or single cell seed hairs, the separate filaments have a natural twist round their central axis which is greatly increased by cultivation, and in wild cotton it is entirely absent. This property, which arises from the unequal drying of the cell contents, is the great physical characteristic of cotton when examined under the microscope, where it presents the appearance of a twisted ribbon with thickened edges. These twists in the fibre give the necessary holding property, and key them into each other when they are twisted into a thread.

A much more marked feature, however, is exhibited in the structure of all wool and other allied fibres where, in addition to a natural curl or waviness in the fibre itself, the whole surface of the fibre is covered with delicate scales or lorications, having an imbricated free edge arranged in more or less ring-like distribution transverse to the longitudinal axis of the fibre, and the free edges always pointing in the direction of the point of the hair. These scales, when the fibres are opposed to each other, come into contact at the free edges, and interlock so that the separation becomes almost impossible, and upon this the remarkable felting property of wool depends.

6. *Porosity and permeability* is also essential, because very few fibres are employed in the natural state in which they are obtained, but dyed so as to give various colours. A fibre, therefore, which cannot be dyed, or which only takes

dye with difficulty, has therefore, for most textile purposes, only a very limited application.

Most fibres, however, whether of animal or vegetable origin, are more or less cellular in structure, with porous cell walls, from which the cell contents can be removed and artificial colouring matter introduced. Even in the case of such a fibre as silk, which is a consolidated gum, it is of more or less colloid character, and can be made to combine with dye stuff, and the colour thus imparted is of the most brilliant hue. Most fibres also have a central cavity which, if not actually open, is of less density and more absorbent than the rest of the fibre. This is well seen in the medulla of wool fibres which acts as a capillary tube for the removal of air and the introduction of colouring matter.

7. *Permanence of structure* is also essential in textile fibres.

It is evident that if they were easily disintegrated, or changed their physical structure so as to become brittle, or lose their distinctive surface, or undergo chemical change under the influence of moderate heat or cold or other climatic conditions so as to cause diminution in strength or organic decay, they would be useless for any kind of textile fabric.

This character can be partly increased in all classes of fibre by the removal, from the inner pores of the fibre, of any unstable cell contents, leaving only those which are not liable to undergo change or treating them with antiseptic reagents which prevent this.

8. *Lustre.*—Although not absolutely essential, a high surface lustre is a valuable adjunct to all fibres.

This quality is seen in its highest degree in silk, and more or less in the long bright wool fibres of the Lincoln or Leicester sheep, and in even a higher degree in the mohair and alpaca goats' hair.

In vegetable fibres lustre is more rare, but reaches a considerable degree of perfection in ramie fibre. Under special treatment some vegetable fibres can be made to rival even silk, as in the case of mercerised cotton, and in artificial silk produced from nitro-cellulose compounds.

9. *Quantity*.—When all the above characteristics are obtained, it is still necessary that, where a large industry is to be based upon any raw material, there must always be a sufficient quantity available. From an economic point of view no process of manufacture can be commercially successful which is subject to interruption in consequence of difficulty of obtaining supplies, and the increased attention which is being paid to the extension of the geographical area over which cotton is cultivated is an evidence of this. The same applies to wool, and indeed to all other raw material, such as ramie, the use of which has been much restricted owing to the difficulty of obtaining a regular and uniform supply of the filasse.

CHAPTER II

CLASSIFICATION OF FIBRES

Classification of Raw Material.—The provisional division of the fibres used in commerce is best attained as a simple arrangement according to the source of their origin; and this is fivefold, although it may be a question which should stand first, cotton or wool, if measured by their relative importance as national industries, but as this volume deals exclusively with cotton it has been given the premier position, and along with it all fibres of vegetable origin. As this classification is only preliminary, reference will only be made to the mechanical structure of the materials, leaving all reference to the chemical differences for subsequent treatment. The classification will, therefore, be as follows:-

I. Vegetable Fibres.

1. Cotton (*Gossypium*).
2. Flax (*Linum usitatissimum*).
3. Hemp including Manila (*Cannabis sativa*)
4. Jute (*Curchorus*).
5. Ramie or China grass (*Bœhmeria*).
6. Miscellaneous bast and other fibres.

II. Animal Fibres.

A. *Appendages of the skin.*

1. Wool.
2. Mohair.
3. Alpaca.
4. Coarse wools, camel hair, etc.

B. *Secretions.*

1. Silk (cultivated).
2. Silk (wild).

III. Artificial Fibres.

1. Lustre-cellulose or artificial silk.
2. Animalised cotton.

IV. Mineral Fibres.

Asbestos.

V. Metallic Fibres.

1. Gold, silver, and other wire.
2. Coated fibres.

These divisions might be greatly extended and further subdivided, and also arranged so as to include botanical and zoological affinities, but for practical purposes the above will serve sufficiently, with the following explanations which indicate some of these relations.

I. Vegetable Fibres.

1. *Cotton* is a unicellular fibre growing on the surface of the cotton seeds, the primary function of which, in the economy of the plant, is to act as a protective covering to the seed and to assist the distribution of the seed by acting as a parachute, which enables the seed to be carried away by the wind and thus scattered over a wider area, until suitable lodgment is secured. These surface fibres are attached to the outer surface of the seed, and, until the seed is almost ripe, are enclosed in a pod or capsule, which contains a number of seeds which are liberated when the

pod opens, and the fibres are then permitted to expand or ripen until they reach maturity, under the action of the air and sun.

The structure of these seed hairs is of the simplest character, since they consist of a single elongated cell, which in most cases is the result of continuous growth and not of several cells, the junction or wall between which has been absorbed, so as to make one continuous cell as in some plant structures. The outer cell wall is a continuous membrane of pellucid material, on the inner surface of which are deposited successive layers of formed cell contents which strengthen and stiffen it in proportion to the deposit. The outer membrane is usually covered with a coating of wax and other preservative materials, which prevent the interpenetration of moisture, and hermetically seal the cell contents except to the permeation of air.

The whole of the central cell cavity or lumen is seldom entirely filled up, and has an irregular oval form in section. When the fibre is dry and the tube collapses on the drying up of the cell contents the lumen appears like a faint line. When fully ripe these fibres are easily detached from the seed and form a fine, elastic, and tenacious raw material usually free from endochrome or colour, and possessing on drying a sufficient twist, arising from the unequal inspissation of the cell contents, to enable them to be turned into an even continuous thread of any required thickness. Many of the fibres allied to cotton, such as thistle-down, cotton silk, etc., have no twist and no rugosity, and so in spite of their high lustre are of no commercial value, except that occasionally they are mixed with wool and used for high lustre fabrics. Many of these fibres, such as Pulu fibre, are multicellular. The length of staple and diameter of the fibre differ widely in

the different varieties of cotton, being only about ¼ inch in Surat and 2 inches in fine Sea Island cotton. Fig. 1 gives a good illustration of fully ripe American cotton fibres. Here the thickness in the cell walls and the irregular twisted form of the fibres are clearly seen.

2. *Flax* is a typical bast fibre, not like cotton, a hair growing on the surface of the seed, but derived from an integral part of its structure. These fibres are obtained

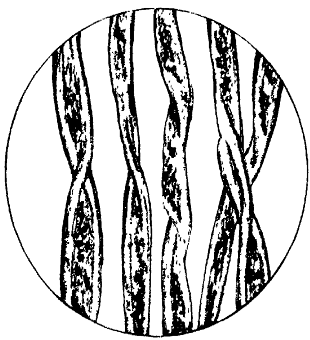


FIG. 1. Cotton Fibres. × 130 diameters.

from the inner lining of the fibrous bark of the dicotyledonous plants. This layer is built up of a reticulated series of lanceolate cells, the ends of which overlap each other so as to form a continuous filament when the vascular bundle is disintegrated. This layer occurs on the outside inner layer called the phloem, as distinguished from the xilem or true wood fibre, which constitutes the principal part of the plant structure, and forms its thick central axis or stem. Each separate fibre is always multicellular, and the cells, from being pressed together by the growth of the

plant, have a polygonal section, and not a circular or oval section as in unicellular free-growing fibres.

The ends are always pointed more or less, and in some cases there are several ends, while the cell walls are always solid and thick from the deposition of the changed cell contents. Fig. 2 represents a typical set of flax fibres magnified 200 diameters seen by transmitted light.

In many of these bast fibres, such as hemp and ramie

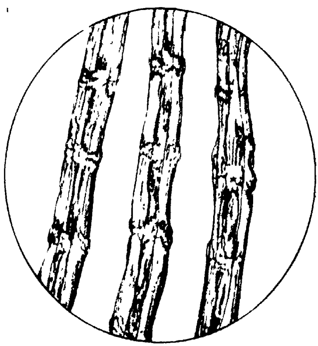


FIG. 2.—Flax Fibres. × 200 diameters.

as well as in flax, there are dislocations or joints at intervals transverse to the length of the fibres. These stiffen the fibrous tube and form thick overlying fissures connected by small short discs or rings, which are useful in catching hold to prevent longitudinal slipping or drawing out when made into filasse.

While these rings give considerable assistance in strengthening the cell walls against the collapse of the tube, they also limit the flexibility, and hence such fibres are not so suitable for dress goods as are the unicellular fibres.

3. *Hemp* is a coarser bast fibre than flax, and is derived from the stem of an annual plant, of which there are many varieties, and is used for coarser fabrics than flax. Fig. 3 shows hemp fibres magnified 200 diameters.

4. *Jute* is also a bast fibre, but derived from a different species of plant, of which there are many varieties, and grows principally in India and the East Indian Islands. The cells are strong and the fibre is smooth and lustrous,

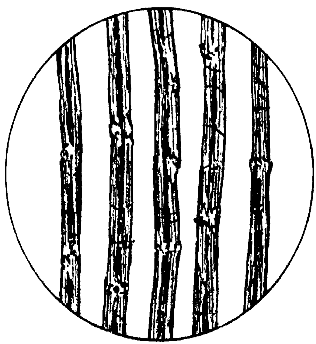


FIG. 3.—Fine Hemp Fibres. × 200 diameters.

but it has no joints or transverse ridges the same as flax and hemp.

5. *Ramie* and *China grass* are derived from two species of a stingless nettle, one of which, the Rhea (*Bœhmeria tenacissima*) is a native of the tropics, while the China grass (*Bœhmeria nivea*) grows best in temperate climates.

The fibres of each of these plants are small in diameter, and of very great strength. When properly prepared ramie is four times as strong as flax and three times the strength of hemp. It also possesses a higher lustre than

any other bast fibre, and the finest qualities rival silk in

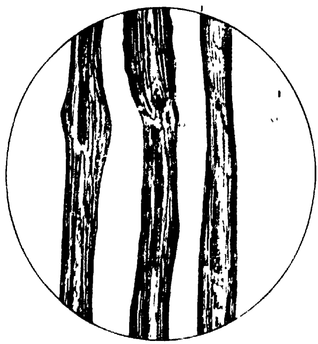


FIG. 4.—Ramie Fibres (seen by transmitted light). × 200 diameters.

this respect. Fig. 4 shows ramie fibres magnified 200

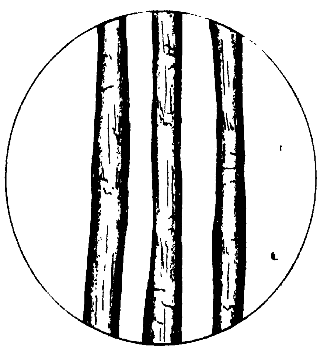


FIG. 5.—Ramie Fibres (seen by reflected light). × 200 diameters.

diameters, and seen by transmitted light, and Fig. 5 fibres seen by reflected light showing the lustre.

6. *Various bast fibres* derived from monocotyledonous plants such as New Zealand flax, yucca, sisal hemp, manila, etc., all of which are similar in structural character to those mentioned above.

Any of these fibres can be obtained in continuous length from a few inches to several feet. The cell walls usually contain a considerable quantity of foreign matter besides cellulose, and these are frequently of a resinous nature, which, unless removed, presents great difficulty to the manufacturer, both mechanically and chemically.

The fibres require much care in preparation, and specially when they have subsequently to be dyed, and their treatment forms a special branch of Chemical Technology to which more attention will be paid in the future.

II. Animal Fibres.

A. Appendages of the Skin.

1. *Wool.*—The chief animal fibres used in textile manufacture are wool, hair, and other fibres which form the outer coating of the skin of various animals, of which they form an outgrowth or appendage.

The most useful are supplied by one order in the animal kingdom,—the Ruminantia or animals which chew the cud, and which includes sheep, goats, camels, cows, etc. Of these, wool is by far the most important. Wool and hair have the same origin, and present identical physical features, which shade into each other and render it difficult sometimes to distinguish between them, as there are woolly hairs and hairy wools.

The chief distinguishing feature is generally that the hair is more rigid and stronger in character, and possessing little curl or waviness which is so prominent in true wool, and it also has a smoother and more even surface; and although both grow on the same animal, yet in the sheep

cultivation tends to minimise the growth of hair and confine it to certain regions of the body, while in the pure breeds the hair is entirely eliminated.

The sheep which belongs to the sub-order Ovidæ is very widely distributed geographically, and produces, as a consequence of the large number of classes into which the sub-order may be divided, a great variety of qualities, all of which are, however, used in manufacture.

Roughly, sheep may be arranged into three classes based on the length of the average fibres.

(1) Short, fine, pure-woolled sheep, such as the merino or the Southdown.

(2) Medium-staple and cross bred sheep, such as the fine combing Australian wools are obtained from.

(3) Long-woolled, bright-haired sheep, such as Leicester or Lincoln breeds.

The wool from any of these sheep exhibits the same characteristics, only differing in degree. The wool fibre in common with hair, from which it is differentiated in degree but not in kind, derives its origin from a follicle or inversion of the cuticle or skin, which forms a deep depression or sac from the bottom of which the fibre springs, and is in muscular and nervous connection with the under layer of the skin.

The shaft of the fibre is formed of closely packed cells, which assume a different form in the different parts of the structure, being less distinct at the point of origin, and changing with the upward growth of the fibre.

When the differentiation is complete three distinct forms are recognised.

(1) The inner or central axis usually consists of large and well-formed globular or oval cells, packed together in a longitudinal direction, and often containing endochrome,

but in the most cultivated sheep this central medulla is entirely bred out.

(2) Round the central axis there is a shaft or cylinder of long lanceolate cells packed close together, and resembling the vascular cells in bast fibres. Upon this cortex depend the strength and elasticity of the fibre. In wild varieties these cells contain endochrome, upon which the colour of the hair depends, but this is also absent in the cultivated sheep, whose wool is light greyish white.

(3) The outer layer covering the surface of the cortex consists of large flattened cells which form a horny sheath or cuticle. These scales are attached at their lower ends to the underlying cortex, and the free ends which are imbricated on the edge are always directed towards the point of the hair.

These scales can slide over each other, without friction, when the fibre is subjected to flexure. When the surface of the fibre is examined under the microscope the edges of these scales are seen as irregular transverse lines, which give the fibre the appearance of being built up of a series of irregular rings like the scales of a palm-tree or slates on a round tower.

These rings are large and irregular, and few in number on coarse wools, and increase in number on fine wools, and upon these depends the felting property of the wool. In many fine wools the scales are continuous round the whole circumference, and give the appearance of a series of cups inserted into each other.

The follicle of the fibre is furnished with oil-secreting glands which lubricate the surface of the hair, and the whole skin is covered with fine openings, from which an unctuous fat or suint exudes, which is secreted from glands enclosed in the skin. In the merino and other fine-woolled

sheep this suint enswathes the whole of the fibres, loosely cementing them together, thus preserving their delicate structure from injury, and preventing the matting of the fibres together when the scales are opposed to each other by the curl of the fibre.

The fibres usually grow in tufts, which are a series of fibres associated together, and forming the locks or staple,

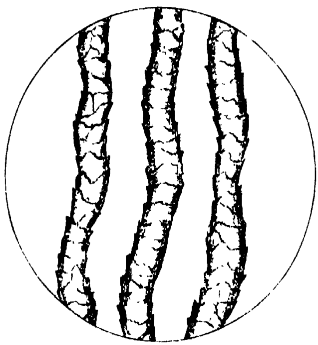


FIG. 6. Fine Wool Fibres. × 300 diameters.

which varies in length in different breeds from ½ inch to upwards of 2 feet.

Fig. 6 illustrates the appearance of typical wool fibres and shows the different thickness of the fibres, and distribution of the surface scales, and also to a slight extent the curl in the wool.

2. *Mohair* is the hair from the Angora goat, which differs from wool by the same characteristics as any other hair, but it possesses a high surface lustre, arising from the size and closeness of the scales with which it is covered. The Cashmere goat yields a similar but finer

hair, and an undergrowth of short wool which is highly valued.

3. *Alpaca.*—This fibre is the produce not of a goat but a small species of goat like camel found in South America, and closely allied to the Llama and Vicuna, which yield a finer and softer hair or wool. The true Alpaca is the hair of the Auchenia Paco, and is usually coloured in tints,

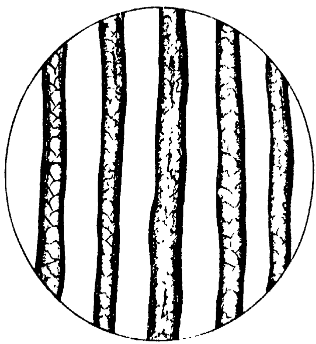


FIG. 7.—Mohair Fibres. × 200 diameters.

varying from greyish white through brown to black. Like other similar fibres it is a mixture of hair and wool.

4. *Camel and cow hair* have all the characteristics of hair as above, but are much coarser, and the scales on the surface are large and closely adhering to the cortex during the greater portion of their length. On the camel there is also a fine hairy wool. Fig. 7 represents the fibres of coarse mohair, which may be taken as typical of this class of fibre.

There are also a considerable number of fibres, such as rabbit-hair, the hair of the beaver, and of the hare, and a

number of similar fur and hair-bearing creatures, whose hairs are used in felting and hat-making, and which present distinctive characters when seen under the microscope. Fig. 8 gives an illustration of the hairs from the kangaroo, the camel, the rabbit, and the curious Australian creature, the *Ornithorhyncus paradoxus.*

B. Secretions.

1. *Silk* is the product of a species of caterpillar, of

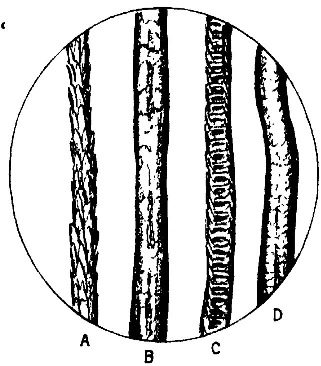


FIG. 8.—Various Hairs. × 200 diameters.

A. Hair of kangaroo. C. Hair of rabbit.
B. Hair of camel. D. Hair of *Ornithorhyncus paradoxus.*

which there are many varieties, some of them wild and yielding tussar silk. Some of the wild varieties are now being cultivated.

The most valued silk is the produce of the mulberry silk-worm, *Bombix mori.* Its use originated in China centuries before the Christian era, and from thence it has spread to all parts of the world which favour its cultivation.

In the economy of the worm the silk fibre is the thread

secreted to form the outer covering of the cocoon which enswathes the chrysalis of the future moth during its pupa state. When the time for forming the cocoon arrives, the worm exudes a viscous fluid from two glands situated within its body on each side. The liquid passes through two ducts in the head of the worm, which enter a common opening, and from it pass into the air, where the fibres coagulate into a firm continuous filament. As the two streams of viscid liquid pass out of this common opening, they are coated with a secretion from two other glands, which cements the fibres together into a double strand.

To obtain the silk, the cocoon is heated before the emergence of the moth to a sufficiently high temperature to kill it. The cocoon is then placed in hot water, which melts the cementing material, and the two filaments can then be unwound, either singly or in combination with each other as may be required, and form the spun silk of commerce. Silk is distinguished for its high lustre, great elasticity, and tensile strength, the latter being almost equal to a metallic wire of equal dimension.

The appearance of the fibre under the microscope is that of a colourless, transparent, and structureless fibre of uniform diameter and free from twist. There are also sometimes visible on the surface of the thread longitudinal striæ or faint ribbed markings like the fluting of a pillar, and especially when the cementing gum is removed.

When gummed and subject to flexure the surface of the fibre, especially in wild varieties, exhibits faint cracks in a direction transverse to the axis of the fibre, arising from the cracking of the gum, which is more brittle than the substance of the fibre. Silk fibres are of great length, and even the waste and short fibres made in the process of

unwinding the cocoon are now worked and spun on special machinery.

The wild silks are of many varieties, and the fibres are generally larger in diameter, darker in colour, and not so easily dyed and bleached, and the strength is not so great in proportion to the diameter as in the cultivated silk. Spider's web, which is closely allied to silk, is sometimes

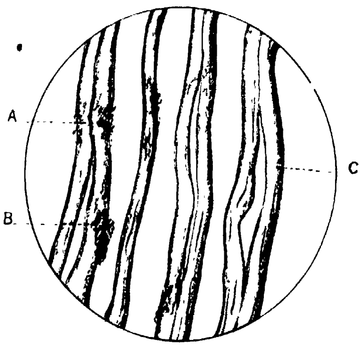


FIG. 9.—Silk Fibres. × 300 diameters.
A, B. Fibres with gum adhering. C. De-gummed fibres

used, and the thread is of a very high lustre and remarkably strong and light in weight.

Fig. 9 shows the appearance of cultivated silk when seen under the microscope. Some of the gum which cemented the fibres together is seen at A and B. De-gummed fibres at C.

III. Artificial Fibres.

1. *Artificial Silk.*—For many years attempts were made to imitate silk by artificial means, such as the coating of cotton thread with solutions of silk, which upon drying gave an artificial surface to the thread. None of these

processes were successful, but about the middle of last century success attended the endeavours of two investigators, M. Chardonet and Herr Lenher, who, each in a different way, were able to produce filaments from solutions of cellulose in various solvents. Cross and Bevan, the great authorities on cellulose, proposed that these compounds should be termed Lustre-Cellulose. The purified cellulose is nitrated, and the nitro-compound dissolved in various mixtures of alcohol and ether, when it forms a viscid liquid which is forced through a capillary tube; and on the solvent being evaporated, and the filament de-nitrated, a transparent colloid thread is formed which closely resembles silk in appearance, and even possesses a higher lustre, but it has neither the strength nor elasticity of silk. It is also more difficult to dye, and when subjected to the action of water it rapidly loses both strength and elasticity, and suffers disintegration.

To get over this difficulty artificial silk is being coated with a solution of real silk, which seems to promise an improvement.

Notwithstanding these disadvantages its use is rapidly extending, and improvements are continually being made. Coarse silk-like fibres called viscose silk are being produced from an alkaline zanthate of cellulose, and solutions of gelatine are being employed in place of cellulose to produce a fibre called Vanduara silk. The evaporated gelatine is then treated to render it insoluble, and this thread more nearly approaches silk than any cellulose compound, as it is all of animal origin.

The great advantage of these artificial fibres is the cheapness with which they can be produced, and the abundance of the raw material. Under the microscope the appearance of these fibres is very similar to silk, and they

cannot easily be distinguished from silk except by their not exhibiting the double strand in the fibre.

2. *Animalised Cotton.*—Cotton threads are now often treated so as to increase their lustre and receptivity to dye, by being coated with solutions of silk, wool, and gelatine which, when the solvent has evaporated, leave a surface sufficiently pliable and elastic not to crack under moderate flexure. The cotton is mordanted previous to coating, so

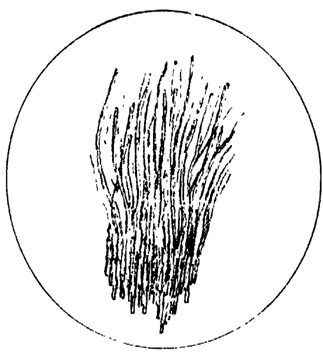


FIG. 10.—Asbestos Fibres. × 7 diameters.

as to increase the affinity of the fibre for the animal coating, and this renders it more homogeneous. This process is called animalising, and the artificial surface has a great affinity for substantive dyes.

IV. Mineral Fibres.

Asbestos, which is a fibrous silicate of magnesium and calcium, is the only mineral fibre used for textile purposes. It is found in strata in rocks in various parts of the world, and especially in Canada, where the asbestos is easily separated from the rest of the strata, and consists of fine

flexible fibres of considerable length and tenacity. The Canadian asbestos has also a certain amount of curl in it, which greatly facilitates spinning into thread.

It has the peculiar property of being able to stand the action of a red heat without disintegration, and hence the yarn and cloth is used extensively where it has to be subjected to a high temperature. Fig. 10 shows the appearance of asbestos fibre under the microscope.

V. Metallic Fibres.

Gold and silver thread, made from fine-drawn wire, are also used for certain purposes in the textile trades. Sometimes they are made entirely from the pure metal, but plated wire by electro-deposition is also extensively used on account of cheapness, such as copper on iron wire, silver on nickel gold on silver wire. Thread is also made by twisting metallic wires along with cotton, wool, and silk, so as to produce various artistic effects in woven fabrics and braids.

CHAPTER III

METHOD OF RESEARCH

Division of Subject.—It would be impossible, even within the limits of a large volume, to consider all the various stages through which cotton is passed in the process of manufacture from the cotton field to the finished product. Such a research would necessarily imply a description of the machinery employed in the mills, and the mechanical details of their construction, and regarding which there are already several works which cover this ground in a thoroughly efficient manner.

This volume is only intended to examine the raw material itself, and look at it as having a mechanical structure upon which its fitness depends, and upon the variations in which certain advantages and disadvantages arise in relation and connection with the process of manufacture, and not upon the mechanical processes to which it is subjected, except in so far as these processes may affect the mechanical or chemical structure of the material in its individual parts. Also to consider, in a similar way, the chemical composition of the fibre and the relation which this bears not only to its tensile strength and other inherent properties, but also to the reactions which occur with the constituents of the fibre, when treated with various

chemical reagents; and especially those which are employed in the bleaching and dyeing of the cotton and the conferring upon it of new properties such as feeding and strengthening the fibre and rendering it more receptive to mordants and dyes, and increasing the elasticity or lustre which it already possesses. It must also be remembered that the investigations into the chemical structure of the cotton fibre, which is largely composed of a carbohydrate called cellulose, have opened up means for its use, in industrial application to the arts, far beyond its employment as in textile fabrics, and have laid the foundation of extensive industries, whose numerous ramifications come within the scope of "the cotton fibre in its relation to technical applications," and must, therefore, have their place in this volume.

The inquiry will also necessitate the investigation of the changes which occur during the growth and development of the fibre, and how they are affected by climatic and meteorological considerations. To give as great definiteness as possible to these various considerations, the subject matter may be examined under four principal heads, each of which is also subdivided.

These divisions are as follows:—

I. The Sources of Cotton.

1. *Species of Cotton Plants.*
    - (*a*) Botanical relations.
    - (*b*) Geographical distribution.
    - (*c*) Histological development.

II. What is the Typical Structure of the Cotton Fibre.

1. *Mechanically.*
    - (*a*) In regard to the arrangement of its ultimate parts.
    - (*b*) In regard to its structural peculiarities.

2. *Chemically.*

(*a*) During the period of development.

(*b*) In the fully ripe fibre.

III. What Variations from the Type Structure are presented.

(*a*) In fibres gathered from the same source at the same time.

(*b*) In fibres gathered from the same plant but in different years.

(*c*) In fibres from different plants grown in different countries.

(*d*) In fibres from the same plant under different treatment.

IV. How far these Variations in the Individual Fibres affect its Use in the Manufacturing Process.

(*a*) Mechanically.

(*b*) Chemically.

The individual fibres of cotton are too small to be properly or clearly examined by the naked eye, even as regards its general appearance and larger features, much less to discern the actual structure and appearance of its individual parts, which are of the most fine and delicate character or to trace the minute markings and irregularities on its surface.

To attain this object it was necessary to employ a microscope, with every accessory and apparatus which modern mechanical and optical skill could furnish; and the microscope used was the very best which could be procured so as to arrive at the best results compatible, not with limited means, but with everything which the microscope could reveal quite irrespective of complexity or cost.

The instrument used was a large compound microscope

of the Nelson model, supplied by C. Baker of Holborn, London. This microscope is in every respect an instrument of precision. Every movement is controlled by mechanical means, thus ensuring that ease and precision of adjustment which is so important in high-class critical work.

The body, stage, and sub-stage are mounted on a massive limb in one piece throughout, thus reducing to a minimum any chance of derangement of the optical axis. The limb itself is mounted on a solid tripod, which secures the utmost steadiness and freedom from any vibration, and is capable of adjustment to any required angle, so that observation can be made by every means of illumination, and under all conditions and angles, both with reflected and transmitted light so as to enable any object to be seen either as opaque or transparent. The principal or upper stage is made specially thin, so that the illumination from beneath can be used at the highest angle, and in addition to the usual rectangular motions there is an arrangement to give an oblique motion and also a complete rotary motion. All parts are graduated, and a glass stage can be substituted for the upper part of the brass stage, so as to enable chemical reagents to be used.

A binocular tube is also supplied as well as a monocular, so that objects can be seen stereoscopically. The draw-tubes are graduated so as to enable any variation in length to be measured and the motion controlled by a fine adjustment. The fine adjustment which carries the optical tube only is actuated by a milled head graduated to $\frac{1}{200}$th of an inch. A sub-stage is carried on the limb below the principal stage, and is fitted with similar motions in every direction, and thus permits the centre of this stage to be brought into absolute coincidence with the centre of the upper stage and the optical tube. This stage carries all

the various forms of condensers, prisms, and polarising apparatus. A direct-vision spectroscope is also used in the absorption experiments.

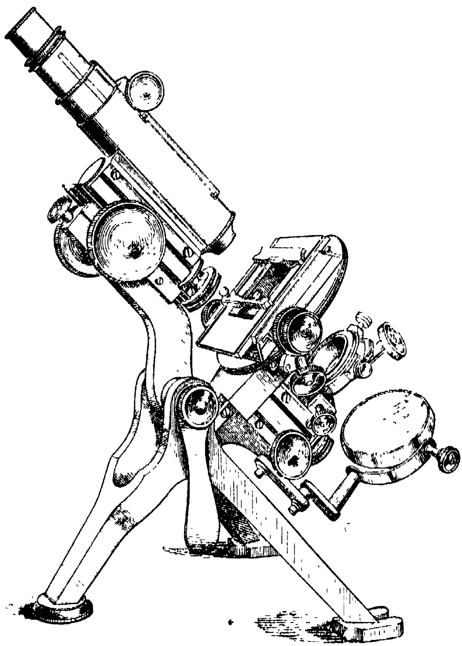


FIG. 11.—Large Compound Microscope. Scale ¼.

This instrument is shown in Fig. 11, in which its appearance and general arrangement are clearly seen.

Special attention was paid to the optical part of the instrument, so as to secure the utmost perfection in definition

free from either spherical or chromatic aberration in either the eye-pieces or objectives. The eye-pieces and objectives were in the case of the apochromatic series made specially to suit each other. The wide range of power attainable by the instrument will be seen from the following table, which gives the focal distance of the objectives and amplitudes of the eye-pieces or oculars combined, measured in diameters.

Object Glass.	Eye-pieces.					
	A	B	C	D	E	F
5 in.	10	15	25	40	50	80
4 ,,	12	19	31	50	62	100
[illegible] ,,	16	25	42	67	83	133
2 ,,	25	37	63	100	125	200
1 ,,	50	75	125	200	250	400
$\frac{1}{2}$,,	100	150	250	400	500	800
$\frac{1}{4}$,,	200	300	500	800	1,000	1,600
[illegible] ,,	400	600	1,000	1,600	2,000	3,200
$\frac{1}{12}$,,	600	900	1,500	2,400	3,000	4,800
[illegible] ,,	800	1,200	2,000	3,200	4,000	6,400
$\frac{1}{25}$,,	1,250	1,875	3,125	5,000	6,250	10,000
$\frac{1}{50}$,,	2,500	3,750	6,250	10,000	13,500	20,000

In addition to this wide range of power every intermediate degree of magnification could be obtained by means of the graduated draw-tubes, and this adjustment was specially valuable in enabling an absolute coincidence to be obtained between the stage and eye-piece micrometer, so as to secure accuracy in the measurement of the diameter or other parts of the objects.

In addition to the usual dry objectives, all of which were obtained from Ross, Baker, Watson, Swift, Powell, and Lealand and other first-class makers, a special set of apochromatic oil-immersion objectives of $\frac{1}{4}$ in., $\frac{1}{8}$ in., and $\frac{1}{12}$ in. in focal length, with a complete set of compensa-

tion eye-pieces, were obtained from Zeiss of Jena. Some idea of the perfection of these glasses may be gathered, when it is stated that they resolved the dots in both directions on the surface of the frustule of *Amphipleura pellucida*, the most difficult object on Moller's test-plate, with as much distinctness as the usual $\frac{1}{8}$ in. dry objective resolves *Navicula formosa*. A $\frac{1}{25}$-in. oil immersion was also supplied, but in the use of the latter no advantage was gained, even when used with a suitable oil-immersion condenser, as the absence of light was not compensated for by increased definition.

Both low and high angled objectives were used, and the observations were made with both polychromatic and monochromatic light, both solar and artificial.

Special attention was given to the measurement of the diameter of the fibres, and to this end a delicate Troughton and Simms Spider Web parallel-wire micrometer was used. The angular reading on the large circular graduated plate was assisted by the use of two reading lenses, of which one has been removed in the illustration shown in Fig. 12, so as to exhibit the slow-motion clamp used to fix the graduated plate in any required position. The working parts of the micrometer consist of an eye-piece within the field of view, of which two very delicate fibres of cobweb are placed paralled to each other. These filaments can be separated from each other by the action of a very fine screw, the head of which is divided into one hundred parts, the several divisions being large enough to enable half to be read with the greatest ease. A fixed index registers these divisions as the screw is turned round. A portion of the field of view within the eye-piece is cut off on one side, at right angles to the cobweb thread, by a scale formed of brass, having notches at its edge like the teeth of a saw or a

comb with shallow teeth. The distance between these teeth from point to point is $\frac{1}{100}$th of an inch, corresponding to the pitch of the screw, and every fifth notch is made deeper than the other four, so as to assist the numeration by the eye. When in use the micrometer is used in place of the ordinary eye-piece. The object to be measured is then brought into such a position that one of its edges

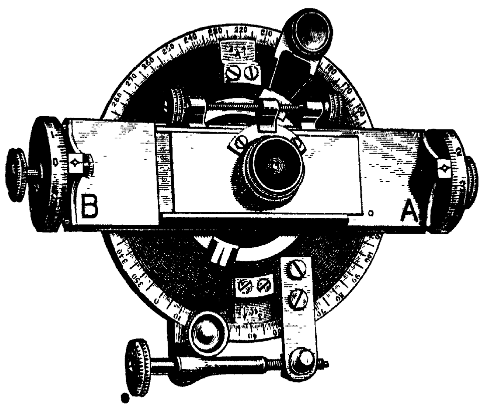


FIG. 12.—Parallel Wire Micrometer.

seems to touch one of the cobwebs, and the other is moved by the screw until it touches the other edge. The number of entire divisions shows how many complete turns of the screw must have been made in passing over the object, while the fractional portions of a revolution are read off the divided head by the fixed index, at A or B. In order to obtain the value of each of these divisions in parts of an inch, it is necessary to use, along with the eye-piece micrometer, also a stage micrometer. This consists of a

graduated scale of very fine lines drawn on glass, the larger of which are $\frac{1}{100}$th and the smaller $\frac{1}{1000}$th of an inch. Fig. 13 illustrates the appearance of this stage micrometer when seen through the microscope.

When the two lines which represent the two sides of these divisions, say $\frac{1}{1000}$th of an inch, are distinctly visible in the field of the microscope, the eye-piece is withdrawn,

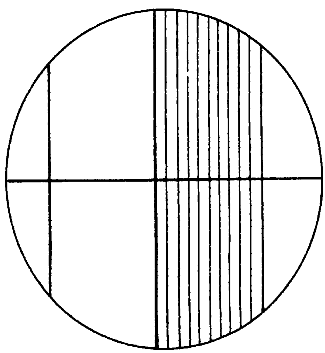


FIG. 13.—Stage Micrometer. × 75 diameters

and the draw-tube pulled out until the $\frac{1}{1000}$th of an inch division on the stage micrometer exactly corresponds to the distance from point to point of one of the divisions of the brass scale in the micrometer. The stage micrometer is then removed, and the size of any object placed on the stage is easily measured, as each division of the brass scale corresponds to $\frac{1}{1000}$th of an inch, and each division read off, on the head of the micrometer screw, is equal to $\frac{1}{100,000}$th of an inch. The value of these divisions may be increased or diminished by making each

of the divisions of the brass scale correspond to larger or smaller divisions of the stage micrometer. The graduated plate on the micrometer allows angular measurements to be taken, as the parallel cobwebs can be turned round in any direction, so as to measure in any part of the field.

In examining the structure of the cotton fibre the degree of magnification which was found most useful was from 250 to 500 diameters, but higher powers were used where examining the details in structure. It is also better to obtain the power by the use of the lower eye-piece and higher-powered objectives than by deep eye-piecing, and the lower-angled objectives are better than high-angled, because they give a deeper penetration, and thus resolve the constituent parts of the object, which are adjacent, both in the horizontal and vertical plane, with greater distinctness.

Method of Preparation.- In order to arrive at the mechanical construction and organic texture of the fibre and its various parts, it was necessary to prepare the specimens so that they could be examined under the most favourable circumstances. The fibres were mounted in the usual way on glass slides with their covering-glasses, and thus each specimen could be referred to again if necessary.

The fibres were first examined in their natural state, that is, in the condition in which they are taken from the surface of the fully ripe seed to which they are attached, and from each part of its surface.

The surface of the fibre in the natural state has a thin coating of oil and wax, which also interpenetrates the substance of the fibre, often entirely filling up the centre cavity or lumen; so that when examined to detect

the various parts of the fibre it is necessary to cleanse it from this cementing and protective material by various methods, including the use of chemical reagents, and also of staining materials, to discriminate the degree of ripeness in the cell-walls and nature of the cells' contents. This cleansing is also necessary, because the wax and oil give a greater and more homogeneous transparency to the fibre, and thus prevent slight structural variations or successive intercellular deposits from being seen. It also, unless removed, prevents the penetration of the reagents and stains, and also of the dyes used in the last experiments.

The following are the methods of preparation and examination which were usually employed:—

1. The fibre was examined in the raw state and without any preliminary treatment.

2. The fibre washed in boiling water and dried.

3. Washing with alcohol and also with a mixture of alcohol and ether.

4. Washed with hot water and treated with a solution of caustic potash and also of soda.

5. Washed with alcohol and ether, and treated with weak and strong solutions of alkali.

6. Treated as above, and washed and treated with cold and warm solutions of zinc chloride, and of iodine and iodide of potassium dissolved in hydrochloric acid, as recommended by Professor Schultze.

7. Cleansing as above and washing with a weak solution of sulphuric acid and of iodine, sulphuric acid, and glycerol.

8. Heated with solution of ammoniacal copper oxide reagent, as prepared by Professor Schweitzer, and method of solvent action observed.

9. Treated with various staining materials, such as

carmine, picro-carmine, hæmatoxylin, eosin, and various aniline dyes.

10. The special specimens reserved for use were mounted in Canada balsam, in glycerine, and in zinchlorin and also dry.

11. A microtome was used in making the sections, which were held together with various binding materials, such as wax.

The fibres were also examined slack and under various degrees of tension, and also after mercerising, bleaching, dyeing, sizing, and also after each process in the manufacture of the thread, and in the cloth, both after weaving in the grey and after the finishing process.

Cotton was also planted and grown in a greenhouse, so as to be continuously observed during the whole process of growth, from the germination of the seed to the full maturity of the plant. Special attention was given to the formation of the ovary and its development; and sections of the seed pod or boll and of the seed, in its various stages, both longitudinal and transverse, were made and examined, so as to arrive at the method of generation and point of origin; and distribution of the embriotic fibres and their gradual unfolding and progress until fully ripe, so as to enable a full history of the fibre to be obtained. This will be detailed at later stages, each under its appropriate heading.

The whole of the plates exhibiting the various stages in development and the appearances of the fibre from the various species of cotton were drawn by the author from the specimens as seen under the microscope. This method was decided upon rather than photography, because, for educational purposes, while the appearance is faithfully represented, they are also diagrammatic; that is to say,

they represent selected fibres, which exhibit the most salient and typical features of the various fibres under the conditions then pertaining, and more closely represent the different characteristics which it is the most desirable to note.

CHAPTER IV

HISTORY, SOURCES, AND BOTANY OF COTTON

IN considering the sources from which the supply of cotton is derived it may not be uninteresting to look shortly at the history of the cotton industry, and see how it has spread from one original centre to every civilised country, and the cultivation of the plant been introduced into many parts of the globe where it is not indigenous; and thus the geographical distribution is now almost universal in the whole of the cotton belt, which extends all round the world, on each side of the equator.

Early Antiquity.—The first use of cotton as a raw material, out of which to make yarn and manufacture goods, is lost in the dim vista of past ages beyond the dawn of history. It is probable that it was in use in India for this purpose 1500 B.C., and long before the Christian era its manufacture had reached a high degree of perfection. Herodotus, writing 445 B.C., says, "In India they possess a kind of plant, which instead of fruit produces wool of a better and finer quality than that of sheep, and from this the Indians make their clothes." Earlier than this, in the book of Manu, 800 B.C., which is a digest of ancient laws, cotton is mentioned so frequently and in such a manner as to indicate that its use, both in the making of yarn and goods,

must have been known for a long time previously. From India the culture of cotton and its use spread to China and Japan, and some authorities are of opinion that the plant originated in India. It is found, however, in one form or another, and in a herbaceous or arborescent form in most tropical countries. Cotton was also in common use for clothing in America when discovered by Columbus, and especially in Mexico and Peru, where it formed the principal article of clothing, as they appear to have been quite ignorant of either silk or flax, although they knew the use of wool.

In Africa, when Vasco da Gama rounded the Cape of Good Hope in the fifteenth century, he found the natives using cotton north of Zanzibar, and skilled in its manufacture, which seemed to indicate that they had been familiar with it for a long period of time. Although it was undoubtedly in India that the first manufacture of cotton goods originated, and where for 3000 years it had almost a monopoly, in consequence of the high state of technical excellence to which the various processes had attained, still, it was probably in use in many regions within the tropics, as the raw material required no preliminary process, except plucking from the seed when ripe, and spinning into thread by the hand, which is common amongst all primitive races which have advanced in civilisation sufficiently to require dress.

Cotton is a sub-tropical plant, and flourishes in suitable localities in a belt, which runs round the whole world comprised within about 45° north and 35° south of the equator, or 3000 and 2500 miles respectively. A glance at the map will show what a large portion of the habitable world is comprised within this limit, since it embraces the whole of China south of Pekin, and the Islands of

the Eastern Archipelago, and the whole of Australia; also the whole of India, Afghanistan, Persia, and Arabia, the south coast of Europe, and the whole of Africa, and in the American continent from the latitude of San Francisco and St. Louis in North America to the southern limit of the Argentine Republic in South America. As within these limits there are included such parts of the British Empire as Australia, India, the South-West African States, and the West Indian Islands, there is no reason whatever that all the cotton required by the Lancashire mills may not be produced within these widely diversified areas, and within which every quality can be cultivated.

Cultivation.—At present the cultivation of cotton on the large scale is chiefly confined to the United States, India, Egypt, Brazil, and China, where, however, it is mostly consumed by the native manufacturers. The various cottons grown in these countries are usually named after the country of origin, such as American cotton, comprising Sea Island cotton, which is the purest variety, and indicates its origin on the shores of the islands of the coast of Florida and Georgia; Indian cotton, known as Surat, after the port in Bombay from which it was originally shipped; Egyptian cotton, the crops of which are grown from American seed in the Nile valley and delta, and Brazilian and Peruvian from South America. Cotton flourishes best when grown on light sandy or loamy soil in districts where there is copious rain during the late spring and early summer months, and fine dry weather afterwards, so as to ripen the boll and dry the cotton. The light soil retains the moisture to feed the plant after the rain has fallen, and does not dry up as in the case of cereal crops. Potash and lime are essential for its growth, and hence it

flourishes best near the coast, where the soil is usually richer in these constituents, probably derived from the sea-spray which is carried by the wind over the adjacent land. If the soil is too deep and rich, the plant is apt to run into too much growth, and produces stalk and leaf rather than cotton. The same happens also in seasons when the rainfall is excessive and long continued. The longest and best qualities of cotton are grown along the shores of the Southern States of North America and in the alluvial soils of the large river valleys where moisture is always found, even in the driest seasons, or can be obtained by irrigation, as in the Nile valley in Egypt, where the soil is also being continually brought from the sources of the river. Irregularity in climate, and deficiency in moisture, lead to the impoverishment and deterioration of the fibre, and tend to irregularity in staple and strength, and in the characteristic twist in the fibre, which is so essential for textile purposes. Although the time for preparation of the soil and the method of cultivation differ in different countries as well as the time of sowing, there is a general similarity in all cases where the plant is an annual, as in the United States, India, and Egypt.

The soil is prepared to receive the seed by ploughing up the land after the clearing away of the old stalks, which are usually ploughed in or burnt and spread on the land so as to restore the normal constituents to the soil. Rotation of crop is also now being largely introduced so as to prevent the exhaustion of the soil, and the cost of artificial manures in any large quantity. Where the soil is stiff and lumpy harrowing has to be resorted to, so as to break up the clods and make the land light and friable. Drills are then employed to make furrows, in which the seed is

deposited, either by mechanical means or by hand. The time of seed-sowing varies with the geographical position of the country. In South America, as in Brazil and Peru, it is usually commenced in January and finished in April. In the United States it usually does not commence until March, and is finished at the end of April, and the same in Egypt; but in India the sowing does not commence until the end of May, and may extend to the beginning of August.

The accepted mode of cultivating cotton is to sow the seed in elevated ridges or beds, varying in distance apart according to the nature of the variety grown, in regard to height and spread. In rich bottom-land alluvial soil, where the plant frequently attains a height of 8 to 10 feet, the drills are 6 feet apart, while in poor land and at the limits of the cotton belt, 3 to 4 feet is sufficient. This space is necessary for weeding and picking purposes, so that the labourers can pass between the rows.

The cotton-plant is particularly susceptible to damage by frost, and hence the greatest care has to be exercised in planting the seed so that it shall not be injured by late frosts, which are as fatal to the young plant as early frosts to the quantity of cotton which can be gathered when the bolls are ripe. Where scientific cotton-growing is practised, hand-sowing is now abandoned, and various forms of machines are used, which deliver the seed, and cover it, when deposited in the soil. The same machine is also, in many cases, arranged so as to deliver a quantity of fertiliser at the same time. In moist warm weather the seed germinates rapidly; and on a large farm the seed first sown is frequently above the ground before the last seed is planted. The average time, in genial weather, may be taken as about a week. The young plants appear in

a long regular line, and any spaces where the seed may not have germinated are replanted at once; and as more seeds are usually sown than are required, the superabundant plants are chopped out with the hoe, and those only left

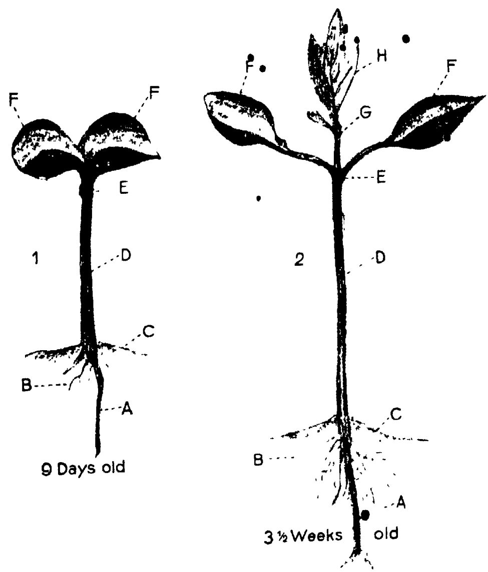


Fig. 11.—Young Cotton Plant. $\frac{2}{3}$ the natural size.

A. Tap root.
B. Secondary roots.
C. Ground level.
D. Hypocotyledonary stem.
E. Primary axis.
F. Cotyledons.
G. True stem.
H. True leaf.

which are about 12 to 15 inches apart. This is always done by manual labour, as skill has to be exercised in leaving the most vigorous plants, and they are never thinned until the plants have made three or four leaves, and attained a height of 5 or 6 inches. Fig. 14 shows

the young cotton plant, in two of its earliest stages—the first when the plant is just a few inches above the ground, and when the stem is only surmounted by the two cotyledonous leaves, before their stalks are developed; and the second when the plant is about three and a half weeks old, when the true stem has grown from the primary axis and the first true leaf and a leaf bud has appeared. This period in the history of the plant is one of great anxiety to the planter. A few nights of sharp frost may necessitate the ploughing up and replanting of the whole field. In the United States warm moist days and nights add, when after-conditions are favourable, several millions of bales to the crop. Too much rain encourages the growth of weed and undergrowth, and constant attention has to be paid to the cleansing of the land by hoeing and ploughing between the furrows, so as to give support to the growing plant without interfering with the freedom of the roots. This constant attention has to be continued during the whole period and until the time of maturity is reached. The soil has to be kept free and open so that any moisture in the air finds its way into the soil, as during June and July this very materially benefits the crop. For the promotion of the best growth of American cotton an increasing temperature during the period of greatest growth is necessary; and Dr. Wright is of opinion that the reason why, when the American seed is used in India, it fails to produce the same staple as in America, is because in India, during this period, there is a decreasing temperature. Perhaps this accounts for the character of the Indian cotton. Maturity usually occurs about the middle of July, and from then until the picking, commencing in August, the land needs little attention. During this period there is usually a fall in the temperature, and every endeavour

is now made to dry up the moisture and harden the soil, so as to sustain the weight of the full-grown plant and

FIG. 15.—Cotton Plant (scale ¾ in. = 1 foot), showing Bud, Flower, and open Boll.

prevent any growth except seed and lint. The first buds usually appear about forty days after the young plant appears above the soil, and the bud opens and the flower expands about twenty or thirty days after the first showing

of the bud. The plant has now attained maturity, although with favourable weather it continues to grow in size, and produces a further crop of flowers and bolls. At this stage the plant presents an appearance similar to the illustration seen in Fig. 15, which shows the plant in bud, flower, and with bolls partly and completely open so as to show the escaping cotton fibre, which forms a white fluffy boll; and the general appearance of a cotton field, when the crop is ready for gathering, can be seen represented in Fig. 16. The flower, which varies in colour from white to red, remains open from three to four days and then drops off; and the boll or capsule enveloped in the calyx increases in size for from fifty to sixty days, when it reaches the dimensions of a small hen's egg, which bursts by the growth of the cotton lint enveloping the seed; and the fibres, released from the boll, swell and expand into a large fluffy ball; and the fibre, dried and matured by the sun and air is ready for gathering. When the boll bursts it exposes three to five cells containing the seeds, which are covered with the cotton filaments, which are firmly attached to the surface of the seed, and longer at the end farthest from the root-point of the seed. The seeds vary in number in each pod from thirty-two to thirty-six.

Although many attempts have been made to introduce machinery for picking the cotton in the field, none can be said, so far, to be very satisfactory, and the bulk of the crop in all countries is hand-picked. This is the busy season, as all must be gathered in as early as possible after the lint is ripe, as early frosts may damage it and thus reduce the crop which can be gathered in. In ordinary seasons the fields are usually picked three times over. First in August and September, then again in October, and if the weather permits in November, and as

far even in to December as the frost is delayed. The yield of fibre per acre may be taken, in American cotton, at about

FIG. 16.—Cotton Field. Photograph taken during the picking season.

200 lbs. on the average on poor land, from 200 lbs. to 250 on rich land.

Ginning.—Before the cotton can be compressed into bales so as to be sent to market, the lint or fibre must be

separated from the seed to which it is attached, as it comes from the field. This process is called "ginning," because the machine which accomplishes this is called a gin, and this has entirely superseded the hand-picking. The seed cotton, as it is picked from the tree, contains only one-third its weight as fibre, as the seeds themselves weigh two-thirds.

Ginning is the first mechanical process to which the cotton fibre is subjected, and it will be easily understood that it is one of the most important, because, as the fibres are firmly adherent to the surface of the seed, it requires a certain amount of force to detach them, and as they are very delicate in structure and easily injured, unless this force is tempered in some way the fibres may be torn away irregularly and their texture injured as well as their strength impaired. If the operation could be perfectly performed the fibre would be removed without injury either to the staple or strength, and also without injury to the seed which, if violence is used, is apt to be broken up; and small pieces with the associated undergrowth of downy hair, which are of no service in spinning, are carried along with the lint and are difficult to remove in the manufacturing process. No machine, however, has so far been devised to accomplish this without one disadvantage or another, and it cannot be expected that this will ever be done, from the following considerations. No two seeds are exactly alike in size or in the same degree of ripeness. The fibres of lint are also unequal in many respects; they are not of the same length or equal strength or equal diameter, and some are more finely attached than others; and frequently, also, there is more or less entanglement, which interlocks the fibres and specially where parts may not be fully ripe, and so they either come away in lumps

forming what are called "neps," or are broken up. No mechanical means can meet all these difficulties at the same time, as no setting of rollers or "doctor knives" or grids can meet every case, and general results, therefore, are all that can possibly be attained, and care taken that the means employed shall be such as to reduce all contingencies which may cause damage to a minimum. Unfortunately some of the gins employed might have been specially designed to do the maximum damage, and these are very slowly superseded by those of better construction.

Saw-Gin.—There are three kinds of gin in general use, the one which was invented as early as 1794 by Eli Whitney, and which is known as the saw-gin, being almost universal in America except for Sea Island cotton. The general principles of this machine may be described as a series of saw-toothed discs, which form a cylinder like a number of fine circular saws, with an interval between each and threaded on to a revolving shaft, which is usually square in section. The toothed part of these discs protrudes through a grid into a chamber filled with the unlinted cotton seed. The bars of the grid are as wide as the interval between the saw discs, allowing a small margin for clearance. The lint becomes entangled in the teeth, and is torn from the surface of the seed and drawn through the grid, where it is removed from the saw teeth by a revolving stripping brush, and carried away to a condenser or receptacle by suction of air. The seeds which remain behind are now a valuable asset to the planter, as they are rich in oil, and are made, after the oil is extracted, into cattle food and other products. The lint accumulated in the condenser is ready for baling. Fig. 17, which is a rough diagram of the working parts of this gin, will make this description quite clear, where A, A are the circular

serrated discs or saws; B, the grids through which the saw passes; D, the hopper which holds the unlinted seed; E, the grid which forms the bottom of the hopper and through which the seeds, after the lint is removed, fall into

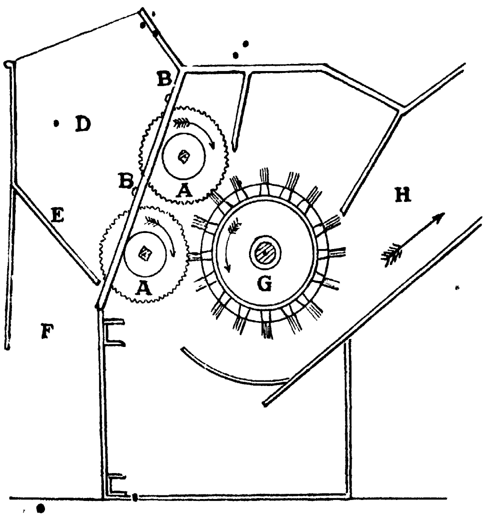


Fig. 17.—Section of Saw-Gin.

A, A. Saw roller discs. B, B. Saw grids. D. Hopper. E. Grid at bottom of hopper. F. Receptacle for seed. G. Clearing brush. H. Exhaust fan trunk.

the receptacle F; G is the revolving brush which clears the lint from the teeth of the saws A, A; and H is the trunk through which the treated cotton fibre is sucked forward by a fan into the cotton room ready for baling.

It will be readily understood from this how such a delicate structure as the cotton fibre can be seriously injured and its strength impaired by such a process,

unless the utmost care is exercised in the setting of the saws and grid, and arranging, that the speed of the saw teeth shall not be too great so as to violently snatch the fibre from the seed. Also that the teeth are not too sharp so as to cut the fibre, or the grid too tight on to the sides of the discs, so that it is doubled up, and broken and strained, and neps and stringy cotton produced. Even when the mechanical parts of the gin are all correct, the state of the cotton must be taken into account, because, if the cotton is too dry, it will be broken up, or if too wet, cannot be drawn through the bars properly, or clings to the saw and is damaged by the cleaning roller. Unfortunately, all these adverse circumstances frequently occur, and especially at some seasons, and the reason why these details are narrated is because almost all cotton which is treated by the saw-gin shows, when carefully examined, damage from one or more of these causes. Looking at the saw-gin from a scientific point of view it seems almost impossible to devise a machine more adapted to injure the lint, and it causes much astonishment that such an antiquated machine should still be used.

Fig. 18 gives an illustration of a few fibres damaged in this way: some of the fibres have split edges and are torn through in the thinnest part, some are entirely severed and left with ragged ends, while others are doubled up and creased until fracture has occurred, which is a clear indication of trapping. This damage occurs more in some seasons than others, probably arising from the cotton being either too dry or too wet, but it may be found in any season in some parts of a bale of American cotton. Similar damage can occur in the carding process, where the cards are in a bad condition, but when the damage is visible before that operation, it can only arise from bad

ginning. This seriously depreciated the value of any cotton, as it is impossible to make even and strong yarn out of it. This seldom occurs either in Sea Island or Egyptian cotton, and also, although the fibre is much coarser than American cotton, it is almost entirely absent in Surat cotton. This arises from the fact that these cottons are almost universally ginned by the use of the other process, viz. the Roller-Gin. If it was not that

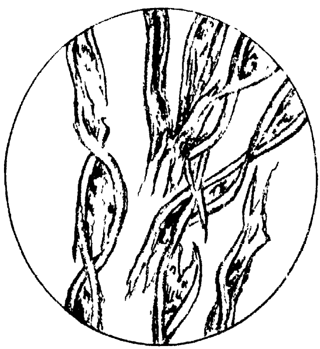


FIG. 18.—Cotton Fibres. × 200 diameters. Damaged by saw-gin.

cotton can be rushed through the saw-gin at a much higher rate than the roller-gin, it is possible that the roller-gin would be much more extensively used. Speed is a most important factor in the determination of the injury to the cotton; and it is in the busy season, when speeds are often increased to far above the safety limit, that the most damage is done. No after process can remove it, and, indeed, such cotton is deteriorated further in every process through which it is passed, and tends to cause injury to the undamaged cotton with which it may be associated.

In steam or water driven saw-gins, as recorded by Mr. C. P. Brooks of Lowell, Mass., in his work on cotton, a gin with sixty saws will turn out 500 lbs. per hour, but he adds, "The staple of the cotton is much better if ginned slower"; and this further, that in the press of the season much larger quantities are got through in the same time with consequently greater deterioration.

Macarthy Gin.—To remedy the defects of the saw-gin, a machine was devised by an inventor whose name it bears. In this machine the saws are entirely done away with, and the construction is as follows. A leather-covered roller is caused to revolve close to the edge of a grid, the same width as the roller, and which grid forms the bottom of the hopper into which the unlinted seed is fed. A reciprocating feed-bar, the width of the roller, pushes at each reciprocation the unlinted seed against the roller, a little below the horizontal centre line of the half circle of the roller. Immediately above the centre line an adjustable "doctor" knife is placed, so as to hold back the seeds when the lint is carried up under it by the revolution of the rough leather-covered roller; and on the far side of this roller, opposite to the doctor knife, a stripping bar or doffer removes the lint from the roller in a continuous film ready for packing in bales. The edge of the grid does not touch the leather roller, but leaves a small interval. This interval is filled by a small beater blade, which is actuated from beneath the grid by a reciprocating arm swivelled to a radius bar which prevents the beater blade ever coming into contact either with the edge of the grid or the surface of the roller. The motion of this beater blade being vertical, and that of the feed-bar horizontal, the seed, when the lint is caught by the leather roller and passed under the doctor knife, is rapidly beaten in two

directions, and so the lint is more easily detached. This removes many of the defects of the saw-gin, but unless the moving and fixed parts of the machine are perfectly adjusted to each other and to the cotton to be ginned, damage is still a necessary result; and where to increase the

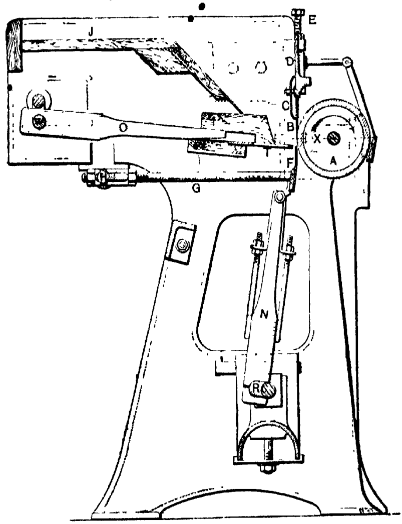


FIG. 19.—Section of Single Macarthy Gin.

output and to remove the excessive vibration two beater blades are employed, which rise and fall alternately, and so balance their motion, an additional source of possible injury is introduced, although not so serious as when the saw-gin is employed.

The structure of the Macarthy gin will easily be understood by reference to Fig. 19, which gives the essential

mechanical features in a diagrammatic form. A is a rough leather-covered roller with a doctor knife, B, on one side, and a doffing or stripping bar on the other side. A steel blade, F, is actuated by means of a connecting rod, N, by means of a crank, R, on the driving shaft. It is also fixed to a rod or bar G, which is centred at H. The seeds are acted upon by the rapid reciprocating motion given to the beater blade by the crank. The repeated blows which they receive soon separate them from the fibres, which are carried forward while the seeds fall on the grid T, through which they pass to a suitable receptacle. It will be observed that F is guided in its path, which is a portion of a circle, having H as a centre, through its connection with the bar G. This bar is also used to adjust the distance of the blade from the leather roller, according to the size of the seeds. For this purpose the ends are screwed and fitted with adjusting nuts, which also lock it in position, when it is once set correctly.

The knife-roller gin is constructed with either single or double leather rollers, and, as the name implies, the fibres are not torn from the seed by the teeth of revolving saws, but drawn off over a knife edge by the action of rollers which draw off the lint. This is simply a more mechanical method of doing in the same way what was done by very crude and primitive means in India long years ago.

The Indian gin simply consisted of two rollers of different diameter revolving with different speed; and the seeds held back by the slower roller had the lint removed by the other roller, and collected on the far side.

Knife-Roller Gin.—This form of gin seems the least objectionable from a mechanical point of view. Its construction and action are as follows:—

A roller is constructed with a series of steel knives wrapped round its circumference, and revolves at the bottom of a hopper into which the unlinted seed is poured. These knives are not, however, concentrically parallel with each other, but wavy, like the detached threads of a non-continuous screw, so that when the roller, round the circumference of which they are wrapped, is revolved, there is a gentle from side to side motion. A leather-covered roller revolves in the same direction as the knives, and catches the fibres of the seed. A doctor knife placed just below the horizontal half of this roller prevents the seeds following the lint, which is removed by a stripping bar or doffer at the side opposite to the doctor knife, and the seeds fall through a grid beneath the knife roller into a suitable receptacle.

The essential parts of this machine are given diagrammatically in Fig. 20. A is the knife roller, seen in section in the top diagram, and the plan below shows the curvature of the knives H H H wrapped round the body of the roller G. They are each separate and continuous round the roller, and not spirally, like a screw conveyor, so that when a seed is caught in between the blades it is simply moved to and fro by the curvature of the knives, and always remains between the same two blades until it is delinted, and then either passes through or over the far edge of the circular grid C. E is the rough leather-covered roller against which the doctor knife D is adjusted, so that the lint is carried forward round the circumference and stripped by the doffing bar F.

For long-stapled cotton the single-roller gin is employed, and this is used universally for Sea Island and Egyptian cotton, and Mr. P. C. Brooks says the production of such a gin is from 70 to 90 lbs. of fibre per hour. There is a

single-roller double-action gin made which answers well for short-stapled cotton, and specially those having a woolly or green seed, and this is the favourite gin for Indian cotton, and gives a production of about 45 lbs. per hour. The double-roller gin can be used either for

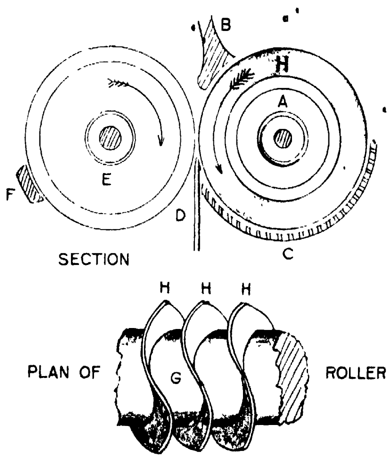


FIG. 20.—Section of Working Parts of the Knife-Roller Gin.

A. Knife-roller.	E. Rough leather-covered roller
B. Back of hopper	F. Doffer or stripper.
C. Grid under knife-roller	G. Knife-roller in plan.
D. Doctor knife.	H Curved knives on roller G.

long or short staple, and will turn out 95 to 120 lbs. of short-staple cotton per hour, or 120 to 140 lbs. of long-stapled. The late Mr. Edward Atkinson of Boston, who was chairman of the New England Manufacturers' Association, made a series of experiments on the ginning of cotton, and its results he gives as follows: "Cotton from the same field is stronger when ginned on a roller-gin

than when ginned on a saw-gin; and while the expense of roller-ginning is rather greater than saw-ginning, there is no doubt that roller-ginned cotton is more valuable, and would bring a higher price in the market, if a supply of roller-ginned American cotton were available, as it will be at once seen how the tugging of a saw at such delicate fibres as those of cotton must break the filament."

Botanical Relations.—The cotton-plant belongs to the natural order Malvaceae or Mallow family, of which the marsh mallow is a familiar example, and the specific genus to which it belongs is called *Gossypeum.*

No plant responds more readily to change in condition in regard to environment, soil, climate, and cultivation, and hence the varying form which it presents as being a perennial in the tree and shrub form, and annual when herbaceous. This great variation in habit and appearance renders it extremely difficult to classify the various species which are known, but they all have botanical characteristics in common, and these may be generally stated as follows, and the enumerations of which are taken from the monograph on the cotton-plant issued by the United States Department of Agriculture.

Gossypeum, herbaceous, shrubby or arborescent, perennial, but in cultivation herbaceous and annual or biennial; often hairy, with long simple or slightly branched hairs, or soft and tomentose, or hirsute, or all the pubescence short and stellate, rarely smooth throughout; stems, branches, petioles, peduncles, leaves, involucre, corolla, ovary, style, capsule and sometimes the cotyledons more or less covered with small black spots or glands Roots tap-rooted, branching, long, and penetrating the soil deeply. Stem erect, terete, with dark-coloured, ash-red, or red bark and white wood, branching or spreading

widely. Branches terete or somewhat angled, erect or spreading, or in cultivation sometimes very short. Leaves alternate, petioled, cordate, or sub-cordate, 3- to 7- or rarely 9-lobed, occasionally some of the lower and upper ones entire, 3- to 7-veined. Veins branching and netted; the mid-vein and sometimes adjacent ones bear a gland one-third or less the distance from their bases, or glands may be wholly absent. Stipules in pairs, linear lanceolate, acuminate, often caduceous. Flowers pedunculate, peduncles sub angular or angular, often thickened towards the ends, short or very short, erect or spreading; in fruit sometimes glandular, bearing a leafy involucre. Involucre 3-leaved, or in cultivation sometimes 4; bracteoles often large, cordate, erect, appressed and spreading at summit, sometimes coalescent at base or adnate to the calyx, dentate or laciniate, sometimes entire or nearly so, rarely linear. Calyx, short, cup-shaped, truncate, shortly 5-dentate, or more or less 5-parted.

Corolla hypogynous, petals five, often coalescent at base and by their claws adnate to the lower part of the stamen tube, obovate, more or less unequally transversely dilated at summit, convolute in bud. Staminal column dilated at base, arched, surrounding the ovary, naked below, above narrowed, and bearing the anthers. Filaments numerous, filiform, simple or branched, conspicuous, exserated. Anthers kidney-shaped, 1-celled, dehiscent by a semicircular opening into two valves. Ovary sessile, simple 3- to 5-celled. Ovules few or many, in two series. Style clavate, 3- to 5-parted; divisions sometimes erect, sometimes twisted and adhering together, channelled, bearing the stigmas. Capsule more or less thickened, leathery, oval, ovate acuminate, or sub-glubose, mucronate, loculicidally deluscent by 3 to 5 valves. Seeds numerous,

sub-globose, ovate or sub-ovate, oblong or angular, densely covered with cotton or rarely glabrous. Fibre sometimes of two kinds, one short and closely adherent to the seed; the other longer, more or less silky, of single simple flattened cells more or less twisted, more readily separable from the seed. Albumen thin, membranous, or none. Cotyledons plicate, auriculate at base, enveloping the straight radicle. Under the influence of variation in climate and culture all the Gossypiæ are prone to run into varieties, and hence, where Linnæus only described three and recognised five, a recent monograph issued from Kew, *Index Kewensis*, recognises forty-two species, and mentions eighty-eight others, which are, however, mostly synonyms of species in common cultivation, many of which are included in the forty-two.

For practical purposes and including all the species which are commercially valuable, the classification adopted by Professor Parlatore, an Italian botanist, may be taken as sufficient, and he came to the conclusion that there are only seven primary species of cotton, and all the rest are only varieties of them. He classed them as follows :—

1. *Gossypeum arboreum*, Linn., found in Ceylon, the Moluccas, Arabia, Senegal, etc.

2. *Gossypeum herbaceum*, Linn., growing in Siam, China, India, Italy, etc.

3. *Gossypeum sandwichense*, growing in the Sandwich and adjacent Islands in the Pacific Ocean.

4. *Gossypeum hirsutum*, Linn., including Siamese, Bourbon, Upland Georgia and Louisiana cottons.

5. *Gossypeum barbadense*, Linn., comprising Sea Island and Barbadoes cotton.

6. *Gossypeum tahitense*, growing in the Society Islands, Tahiti, etc.

7. *Gossypeum religiosum*, Linn., including Peruvian and other cottons with seeds in adherent files.

Many competent botanists, however, are of opinion that there are only four primary species, and all other forms are only varieties of one or other of them.

They are:—

1. *Gossypeum arboreum*.
2. *Gossypeum herbaceum*.
3. *Gossypeum peruvianum*.
4. *Gossypeum barbadense*.

Gossypeum arboreum is found extensively distributed in the Asiatic cotton belt, and forms a hardy tree-like plant growing to a height of from 15 to 20 feet, which in the wild or uncultivated state is perennial. The flowers are purple or rose-coloured, and usually have a large dark purple spot at the base. The fibre presents two forms, one with long (about an inch) and silky fibre, overlying a short dark green or almost black down. Little of this cotton is, however, produced; and according to Watt, as it is usually found near temples, and in gardens where it flowers most of the year, and the use of the fibre is said to be restricted to making thread for the turbans of the priests, it is known as *Gossypeum religiosum*.

Gossypeum herbaceum is also a native of Asia, and some botanists are of opinion that *Gossypeum hirsutum* is only a variety of this species, since the variations in habit and structure are very slight. All botanists think, that although very similar, *herbaceum* is of Asiatic and *hirsutum* of American origin, and originally confined to Mexico. All the Indian cottons such as Surat, Hingunghat, Broach, Tinnevelly, Dhollerah, Amrawuttee, etc., belong to this species, and all the native African cottons. From the former the Indian or Surat cotton is derived, and from the

latter most of the cotton from the Southern United States known as Upland cotton. The plants seldom reach a height of more than 7 feet, and bear a white or yellow flower with a purple spot at the base which becomes reddish at maturity. The fibre, when cultivated, is long and silky, and along with it there is a considerable undergrowth of fine down. In many districts this species becomes very shrubby in habit, and very hardy in constitution, so that it flourishes well under a wide variation in condition, and can be cultivated in a wider range of latitude than any of the others.

Gossypeum peruvianum is indigenous to South America, as the name indicates. The flowers are yellow like *Gossypeum barbadense*, and the pods each contain eight or ten black seeds arranged in adherent files, and the fibre is strong and coarse, and specially in what is known as rough Peruvian. The plant, though shrubby, is almost arborescent, as it reaches a height of from 10 to 15 feet. The fibre is strong and robust, and possesses a considerable reluctance to torsion, so that it is valuable in imparting to yarn spun from it a "loftiness" of character in the yarn which enables it to "fill in" when made into goods, which is of great advantage in many cases where apparent substance has to be combined with lightness in weight.

Gossypeum barbadense is the most valuable of all the species, being that which produces the long silky-haired Sea Island cotton. It has a yellow flower, and the seeds are small, black, and quite smooth, and remarkably free from all undergrowth of fine short hairs, which in some species detract from its value. Those botanists who are of opinion that *Gossypeum hirsutum* is of American origin and not of Asiatic origin believe it to be only a variety of this species, from which it is easily distinguished, by having

a white or faintly primrose flower and a hairy or woolly seed. The colour is a light cream, and it is distinguished for the length, fineness, and evenness of the fibre, and for the number and uniformity of the twists, which are greater and more regular than in any other variety. The fine Egyptian cottons known by various names, such as Gallini, Ashmouni, and other fine grades, are grown from this seed, and have a darker shade of colour varying from golden straw to dark brown, although some botanists are of opinion that the brown cotton is a native and not an imported variety allied to *Gossypeum herbaceum*. It is found, however, that the same seed grown in different districts in Egypt assumes a different colour in the lint. The white Egyptian cotton is mostly grown from the same seed as the Upland American, which is a variety of *Gossypeum hirsutum*.

Although these botanical divisions are of great interest from a scientific point of view, from a commercial standpoint the division of the cotton-plant, as grown in different parts of the world, may be said to present three different characters, viz., herbaceous, shrub, and tree cotton, and from one or other of these the world's crop is obtained, and the differences in the various characters of the fibre present similar peculiarities from whatever source they are derived, differing only in degree. These differences are of great value in determining the purposes to which they can be applied, and the character which they give to the yarn and goods made from them, and these will be considered later on.

Improvement of Cotton.—The cultivated cotton, as derived from any of these sources, is very different from the product of the wild plants from which they originally sprang. As in the case of all scientific culture, great

improvement of every part of the produce and structure of a plant may be attained by careful attention to the selection of stock and the provision of suitable soil and environment. No plant responds to these conditions more readily than the cotton-plant, and the whole character of the form, habit, and produce of seed and lint may be greatly modified and improved by alteration in soil, climate, treatment, and fertilisers during even a few successive crops. The converse is also unfortunately true; and no plant deteriorates more rapidly than the cotton-plant, and with it the character of the lint, when proper and efficient cultivation is neglected and the soil becomes impoverished through want of artificial manures. This rapid response to changed conditions is therefore not an unmixed benefit, because it causes those variations in the character of the crop from year to year, which render it impossible to produce exactly the same quality of yarn and goods without a continuous readjustment of qualities in the commercial standard. This is well known to both masters and men in the manufacturing districts, and is often the source of both annoyance and loss; as the crop of one season often makes more waste and spins worse than that of another, even where the appearance of the cotton seems to be the same, because the fibres are less robust and weaker in strength, and the difference in value between the same standards, in different years, is often much greater in proportion some years than others. This is causing attention to be drawn to the fact that cotton is capable of being rendered more immune to climatic variation by cross-fertilisation, in the same way that the proper selection of sire and dam and the introduction of fresh blood by the cross-breeding of different breeds of sheep has enabled the farmer to greatly reduce the variation of wool from the same sheep, during different

seasons, and produce a sheep more fixed and stable and hardy in character. In relation to the cotton-plant there are four ways of accomplishing this, which closely correspond to the methods adopted by the sheep farmer.

1. Selection of the best individual plants for the original stock.

2. The selection of the seed from the earliest maturing bolls of the respective plants.

3. The planting of the seed in suitable soil artificially fertilised.

4. Cross-fertilisation with other species, which possess the qualities desired to be introduced.

1. In every cotton-field there will be noticed a considerable difference in the appearance of the individual plants, although they may all be derived from the same class of seed, and have been sown at the same time. Some of this variation may be accounted for by local variation in the soil and moisture, but in general it is the result of more robust and vigorous growth on the part of the individual plant, and shows itself in the strength of the stalk, the size of the leaves, and the exuberance of flowers and bolls. These plants usually flower earlier, and the bolls and lint mature earlier and more simultaneously than those of the weaker plants. The seed gathered from these plants usually transmits more or less of the characteristics which distinguish them to the next crop, and by this means a considerable number of local variations in the plant have been obtained, especially in the United States, where they are mostly known by the name of the originator who made the selection.

In Bulletin 33, issued by the United States Department of Agriculture, above 120 of these improved varieties are named, each of which has superior qualities to the original

stock from which it was derived, either by having longer staple in the lint, or a larger production per shrub as measured by the weight of crop per acre, or possessing a more even staple and less liability to shedding of bolls, or greater immunity to disease and the attacks of parasites. In some cases there was also an improvement in colour, and also an earlier maturity of the cotton which enables it to be gathered, even if the fields are picked over more than twice, before the early frosts appear. In all cases, as a rule, the successive crops, if a continued selection is observed, tend to accentuate the advantages and become more fixed and approach nearer to the desired standard; but unless constant vigilance and weeding-out is maintained deterioration is sure to set in, and the variety may "run out," as it is termed. The high price of cotton, which tends to encourage "weight" rather than "quality," greatly mitigated against the adoption generally of this high-class culture, but there can be little doubt, as has been proved at many experimental stations, that by this means alone a much higher standard of cotton can be obtained with benefit both to the grower and consumer.

2. Even when the seed is selected from the best and most vigorous parts, it is found that, as a rule, the best results are attained by taking only the seeds from the earliest maturing bolls which are collected during the first pickings; and the Bulletin 33 states that it is from this method of selection that some of the most famous of these improved varieties, such as "Drake Cluster," "Jethro," and "Southern Hope," have been obtained, which are distinguished by their early maturity, longer fibre, more uniform crop, and greater productiveness when grown in suitable soil with congenial fertilisers. This is really the selection of the best part of the best, and giving it the

highest culture so as to bring out the best that is in it, a maxim which ought to be laid to heart by all cotton-planters, and applies to every country where cotton can be grown.

3. When proper selection has been made of plant and seed, it is also necessary to study the nature of the soil and manure best adapted for the full development of the plant, because the cotton-plant responds very readily to change in this respect. Many varieties, which in rich bottom land, river soil, produce a strong long-stapled silky fibre, entirely lose this characteristic when grown on poor lean soil, on upland hilly districts, where the mineral food in the soil is either small in amount or unsuitable in form. The converse is also the case, but not so marked, because cotton removed from a lean soil is apt to run more to plant growth than to improvement in the better characteristics of the better cotton, and can only have them restored or produced by a fresh process of cultivated selection. By judicious fertilisation with manure adapted to the soil, not only may the character of the fibre be improved, but the maturity of the crop hastened, and the period between sowing the seed and in-gathering of the lint so shortened that the geographical area within which cotton can profitably be grown can be materially extended so as to widen the cotton belt beyond its present limits.

4. Sometimes, even when the best has been selected from any individual variety of crop, it is not enough, because it may be of advantage to secure the good qualities of another variety so as to combine the advantages of both. Just as the cotton-spinner, in order to produce certain qualities of yarn, makes a "mixing" or "blend" of different characters of cotton derived from various sources, so the cotton-grower can make a natural mixing by cross-

fertilisation of the ovaries of one species of plant by the pollen of another variety, so as to obtain greater silkiness or more strength or earlier maturity in the hybrid. This is frequently done, and with considerable success, because the character of the generative organs in the cotton-plant renders this comparatively easy.

This process, however, requires great care and patience and perseverance, as may be judged by the following extract from the Bulletin 33. "Although cross-fertilisation is the surest method in the production of new varieties, it is largely work in the dark, as the plants resulting from the crosses may fail to show the good qualities of either parent and have all the weak points of both. Out of a hundred crosses, it is seldom that more than one or two plants will show the combination which is desired, and even when a promising plant does appear, its character is not yet fixed, and several generations must be grown before it will assume its permanent form and demonstrate its true value. Although the plants from a single line of crosses, as fertilising 'Peterkin' with 'Allen,' will vary widely, still it is a general rule that the character and the habit of the future plant will be that of the female parent, while the lint, the boll, and its contents will be more like those of the male parent." Even when all this is done it will still be necessary to exercise plant selection as in the first method of improvement and careful cultivation to secure the best results. The introduction of cotton-planting over a wide area of the British Empire, which is at the present time attracting much attention, affords a good opportunity for inculcating the lesson that where comparatively small areas are under cultivation and the distance from the market often great and means of transport small, it will pay best to study quality rather than quantity, as even under any

circumstances this will give a preference in the market, and thus in bad times and when prices are low, secure a greater stability in regard to readiness of sale, which is always a great advantage, and specially in new countries where capital is not very abundant.

CHAPTER V

ORIGIN AND DEVELOPMENT OF THE COTTON FIBRE

THE story of the origin and development of the cotton fibre is really the history and development of the flowering part of the plant, from the bud to the full development of the boll and the liberation of the cotton fibres.

Wild Cotton.—A variety of wild cottons are found both in the Old and New Worlds, and while the fibres are coarser than in the cultivated cottons and possess less of the characteristic twist, they all seem to have, as pointed out by Sir George Watt in his classical work on the *Wild and Cultivated Cottons of the World* (Longmans, London, 1907), a red-coloured woolly coating on the testa of the seed. In some this assumes the condition of a short dense velvet, called the fuzz. In others there are two coats of fibre, an undercoat, the fuzz, and an outer coat, the true fibre or floss. In one variety there is no fuzz but a distinct floss. In the fuzzy-seeded cottons it is difficult to separate the floss from the seed, but in the naked-seed variety this is easily accomplished. These peculiarities, Sir George believes, are almost sub-generic in value, and there exist several purely wild cottons of each class, as well as many

cultivated varieties. Wild naked-seed varieties seldom exist in countries where there are fuzzy-seeded cottons, and the variability of a fuzzy-seeded into a naked-seeded variety is a certain proof of hybridisation—a case of reversion. A tinge of reddish shade in the floss is a characteristic of all wild cottons, and where it appears in the cultivated varieties it is also a case of reversion.

Botanical Relations.—Taking the American Upland cotton, *Gossypeum herbaceum*, as the type of the cultivated variety, to relate the history of the fibre, it is necessary to note that the earliest appearance of the bud, or square as it is termed, is usually on the average about forty days after the plant first appears above the soil. It takes its rise from the tree stem and its branches, as a rounded swelling, which most frequently occurs, but not always, at such points on the shrub as form a fork, or where they make a point of departure in a new direction, as at the joint where the leaves are attached. The bud gradually swells and enlarges until it is completely detached from the branch except by a short peduncle or stalk. In its earliest stages the sepals which form the calyx or outer envelope of the bud entirely overlap each other and the bud, but can early be distinguished by their deeply dentated or imbricated form at the extremity. They are formed, as are indeed all parts of the flower, from modified foliar leaves, like the ordinary leaves of the plant, but simplified in structure and adapted to the means of reproduction. These sepals have the same vascular structure as the ordinary leaf, but have more simple ramifications; that is to say, that the xylem and phloem of the sepals, while corresponding in position to the same parts of an ordinary leaf, have the mesophyl of more uniform parenchymatous structure throughout. Fig. 21 illustrates these various stages of growth of the

cotton flower from the earliest bud, 1, to 6, the fully

FIG. 21.—Cotton Flower Bud.

1. Bud 2 days old.
2. Bud 5 days old.
3. Bud 10 days old.
4. Bud 15 days old.
5. Bud 20 days old.
6. Bud 25 days old.

developed square ready for unfolding, at intervals of about

five days, when the sepals are just opening, and showing the tops of the petals enclosed within them which form the corolla.

All flowers consist of one or more series of organs placed round the tip of a peduncle or pedicel which constitutes a floral pillar, while the organs are termed floral whorls. In the case of the cotton flower it is what is termed "complete," because it contains the typical number of floral whorls arranged in symmetrical order round the top of the floral receptacle, which forms the summit of the flower stalk. These whorls differ materially in their structure in the different parts of the flower, although they are all modified forms of leaf, and their function is to enable the plant to multiply by the formation and fructification of seeds.

The Cotton Flower.—In the cotton flower, as in all complete flowers, these whorls are four in number, and are arranged in their order from the outside to the central axis of the flower in the following manner.

1. The calyx, as described above, consisting of separate sepals or leaves, which are green in colour and are attached to the base of the floral pillar. They form an outside protective sheath to the young bud by overlapping each other and folding together at the top, and only open when the flower is ready to bloom, when they fold back so as to permit the petals of the corolla to expand.

2. The corolla, or the true flower whorl, which forms the coloured part of the flower, and consists of petals, which in the cotton flower are usually five in number, and the object of which seems to be to attract the insects which are necessary to assist in the fertilisation of the seed.

3. The stamens, which consist of filamentous stalks, and which in the cotton-plant are fused into a ribbed vascular

tube, to which are attached the anthers bearing on their surface the pollen or fertilising dust.

4. The innermost whorl or pistil, as it is called, which consists of a bundle of vascular tubes coalesced into a pillar which forms the central axis of the flower. This part of the flower is the last to form, and is surrounded on

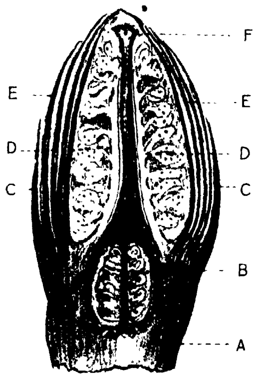


FIG. 22.—Longitudinal Section of Cotton Bud. × 7 diameters.

A. Apex of flower stalk.
B. Ovary showing septum.
C. Sepals of calyx.
D. Filamentous stamen stalk with anthers attached.
E. Petals of corolla.
F. Pistil or stigma.

all sides by the stamens, and exhibits the greatest modification or departure from the ordinary leaf structure of any part of the organs. It is hollowed into a cavity at the base, the walls of which afterwards form the carpel or seed-case, which forms the ovary where the ovules or seed-germs are developed. From the walls of the ovary, the pistil rises upward by a tapering shaft or style, which terminates just above the level of the stamens in an

enlarged knob or surface which has a pitted or roughened summit called the stigma, and which secretes a gummy exudation to which the pollen, when blown by the wind or carried by insects, adheres and thus secures the fertilisation of the ovules in the ovary at its base.

Fig. 22 is an illustration of a young cotton bud in longitudinal section and before unfolding, in which all the separate whorls of the flower are distinctly seen, closely packed into a compact form. Commencing at the bottom of the bud, it is seen severed from the stalk a little above the point of junction with the branch. A is the receptacle or the apex of the stalk to which the whorls are attached. B is the ovary, with one of the division walls, or septa, distinctly visible, to which the ovules are attached in a double row, one on each side. The involuted edge of this wall forms the placenta. C shows the sepals which form the enveloping calyx. E exhibits in section the petals, which form the second whorl, and which, being enfolded round the stamens, in this early stage, form a protective covering to the delicate anthers which are attached to D, the stamenal pillar or tube, which surrounds the pistil F with its terminal knob or stigma.

A horizontal section of the flower, only rather higher magnified, is seen in Fig. 23, where the section is taken through the floral pillar just at the base of the petals which form the corolla, and which are seen in section at A attached to the floral pillar B. The vascular bundles through which this floral pillar is fed are seen at F, and in this case are ten in number. In the central axis of this floral pillar, and forming the base of the pistil, the ovary is seen in section to be divided into three compartments. The ovary wall is seen at E. Three inward processes of the ovary wall, which form these compartments

or cells, each terminate in an enlargement of triangular form, when seen in section, and form by the inversion of their edges the six C placenta to which the ovules D or rudimentary seeds are attached. The form of these ovules is pear-shaped, more or less in the longitudinal, and circular in the horizontal section. They are arranged in two rows in each of the compartments of

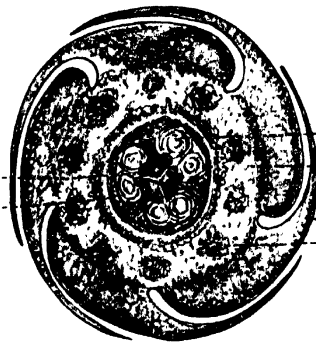


FIG. 23.—Transverse Section of Cotton Bud. × 7 diameters.

A. Base of petals of corolla.
B. Base of floral pillar which carries the sepals, petals, and stamens.
C. Placenta with ovules or seeds attached.
D. Ovules.
E. Wall of Ovary.
F. Vascular bundles.

the ovary, and usually about six seeds form each row, which grow twelve to each compartment or thirty-six in the three compartments. These ovules are seen in section at this stage to possess three coats or envelopes surrounding the nucellus which forms the inner substance of the ovule, and which after fertilisation, correspond with layers in the cotton seed, from the outer of which the cotton fibre grows.

The cotton-plant is a free flowerer, and cultivation increases this habit. Also when flowering has once com-

menced it continues to flower throughout the season until

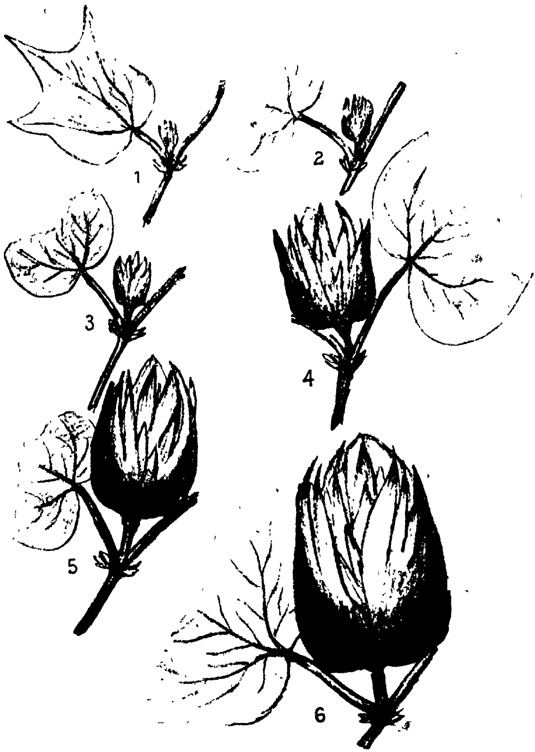


FIG. 24.—Cotton Flower Bud from Earliest Stage to Opening.

arrested by the cold weather or frost. Flowers have been known to open as late as September, but in that case the

boll never reaches maturity. Thus at the height of the season, bud, flower, and fruit may be seen all on the tree at the same time. Fig. 24 shows the gradual growth of a cotton bud or square, from its first appearance in 1 up to the point of its maturity in 6, when it is just ripe and ready to open.

Although somewhat irregular in its growth the cotton tree, when in full bearing, has an exceedingly attractive appearance. The flower when opening is usually white or creamy white or yellow, with a slight tinge of purple or purplish red at the base of the petals, and these change to a deeper reddish hue on the third day, just before the petals are shed. The colour of the flower depends on the variety of the cotton.

Fig. 25 shows a twig taken from a flowering bush just when the bloom is fully open. The large handsome yellow petals are seen surrounding the inner whorl of stamens with the pendent anthers, and in the centre the stigma of the pistil. On the same twig are seen two flower-buds, the lower one rapidly maturing, and the upper with the petals of the corolla already protruding above the calyx and ready to expand in a few hours. Although this example was sketched from a flower of Egyptian cotton, probably *Gossypeum peruvianum*, it may be taken as typical generally of the other varieties, although they differ slightly in the form of the petals, as some have a more irregular edge, and indeed this occurs on the same plant; also the colour differs. The frontispiece to this book is drawn from a group of flowers of different species, and shows the bud, flower, and ripe boll shedding the fully matured seeds with their fibrous covering. As soon as the flower is unfolded, the transfer of the pollen from the anthers to the stigma quickly ensues; and the object of the coloured corolla and

the whorl of stamens and anthers being accomplished, the flower rapidly fades and the petals and anthers fall away,

FIG. 25.—Cotton Flower and Buds.

generally at the end of the third or beginning of the fourth day after the opening of the flower.

The Ovary and the Ovules.—Of the marvellous mechanism of the reproductive organs of the flower, the method of fertilisation of the ovules by the pollen tubes,

and the changes which the cell-contents undergo afterwards, this treatise can take no account, except in so far as they relate to the origin and growth of the lint which covers the seed. These changes are very rapid, and their course constitutes the life-history of the ovules. Before fertilisation they have been formed by an outgrowth from the inner margin of the re-turning head of the placenta, which had its origin in a process from the inner wall of the ovule sac. They are arranged in a three-cell ovary in two lines, in a vertical direction in the cell, and are each attached to the margin of the placental wall by a short stalk which is termed the funicle.

In its earlier stages the ovule presents a rather complicated structure. In the centre, and near its lower end, is a series of fine cells called the nucellus, and from the lower part of this nucellus, and enclosing it on all sides, there arise three envelopes or cellular sacs differing in composition and appearance, which will be best understood by reference to Fig. 26, where is represented one of the ovules seen in section of the ovary in Figs. 22 and 23, only with a considerably higher amplification.

A shows the nucellus surrounded by the three enveloping sacs,—(1) the coat B which consists of a series of irregularly disposed starch and other cells, containing nutrient matter, which after fertilisation has taken place forms a store of food for the developing embryo; (2) seen at C is the rudiment of the palisade layer, which in the full ripe seed, after undergoing a consolidating process, forms the pericarp or hard shell of the seed, and contains, when there developed, a green, greenish-brown, brown, or black pigment matter which gives the colour to the seed when ripe. The parenchymatous cells, of which this palisade layer is formed, differ in form from the starch

layer, being much more elongated, and having the major axis of the cells arranged radially to the curvature of the starch layer beneath, and in symmetrical order. This layer forms the base upon which rests the outer layer; (3) seen at D is formed of loosely arranged spongy parenchymatous cells, many of which have well-defined nuclei, and these form the matrix out of which the fibres ultimately take their rise, and from which their nutriment

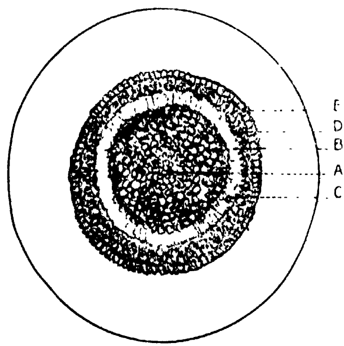


FIG. 26.—Transverse Section of Ovule Unfertilised. × 30 diameters.

A. Nucellus C. Palisade layer.
B. Starch Cells. D. Spongy parenchymatous layer.
E. Cuticle or fibre matrix.

is derived. The outer layer of this coat E is formed by a well-defined cuticle which protects the more active cells beneath, from which the young cotton seeds spring, and which form the fibril layer.

Growth of Seed.—Concurrent with the complete formation of these layers the spongy parenchymatous layer is saturated with protoplasm, and the cells are in a highly sensitive stage and ready for the reception of the dynamic nuclei which are conveyed by the pollen tubes down the

pistil, where they enter the ovary and so reach the ovules.

It may be noted here that just as the flowers of any individual tree do not all reach maturity at the same time, so there is frequently also a want of correspondence in the various organs of the same flower, so that it often happens that the ovules of one flower are fertilised by the pollen from another flower, and also from that of an entirely different tree. This cross-fertilisation is of great advantage in maintaining the strength and vitality of the seed, just as the introduction of fresh blood into a herd of sheep, from time to time, is practised in scientific farming, and has greatly improved the breed of sheep.

As soon as fertilisation takes place structural differences in these several layers soon begin to be apparent. The innermost or starch and nutrient layer begins to be absorbed by the developing embryo, and at the same time the palisade layer undergoes consolidation and pigmentation, and also the active parenchymatous cells, which lie immediately below the cuticular layer, commence to elongate and to force themselves up through the cuticle, when they appear above the surface as elevations or buds, which form the base of the fibres now first generated.

It is interesting to watch under the microscope how these changes come about. Some of the cells in the fibril layer commence to extend, and from a compressed circular form become oval, with the longitudinal axis at right angles to the surface of curvature of the seed. Within the cell also the protoplasm, as can be determined by the position of the nucleus of the cell, seems to concentrate against the outer walls of the cell and to become thickened or coagulated and less mobile; and this forms the first

deposit of the inner surface of the thin transparent wall which bounds the cell and forms its outer sheath or pellicle. This also forms the base upon which secondary deposits take place, which thicken and strengthen the fibre, and within which the formation of endochrome occurs, wherever the cotton is in any degree coloured, such as in Egyptian cotton. The method or plan in which these secondary deposits are laid or arranged on the cell-wall will be considered later on when examining the action upon the fibre and its cell-contents with various chemical reagents which enable these deposits to be seen. As the young fibre by its growth is pushed out they are compressed together by filling the interior of the seed-pod with a tangled plexus of unicellular hairs in various stages of growth. At this period the whole surface of the fibres, and the spaces between them, are filled with exuded cell-contents, which keep the surfaces of these delicate fibres moist, and enable them to move over each other without excessive friction, so that they are not injured, just in the same way that wool fibres are preserved by the suint exuded from the skin of the sheep and thus prevented from felting. This tangled plexus of hairs also forms a protective covering to the developing embryo within, and, as they increase and fill up the space between the pericarp, which is being gradually formed out of the palisade layer and the outer carpel which contains the whole, they exert continually increasing outward pressure, which assists to burst open the pod when the period of development is attained.

The fibres continue to grow until all the nutrient matter in the cotton matrix is exhausted, and nothing but empty cells remain. The first appearance of the young fibre buds always occurs on the surface of the fibril layer,

at the end of the ovule farthest removed from the point of attachment of the ovule to the placental matrix, and from here spread over the whole surface, and are always the longest at this end, gradually becoming shorter as the point of attachment is reached, so that at the root end of the seed there is only a scanty growth, and in some cases the end where the funicle is separated from the

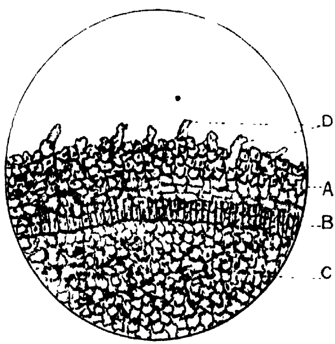


FIG. 27.—Section of Outer Layer of Cotton Ovule. × 75 diameters.

A. Epidermal layer or fibre matrix. C. Starch cells.
B. Palisade layer. D. Embryo cotton fibres.

placenta is quite naked. This is the birth of the cotton fibre.

This change will be better seen in Fig. 27, which gives an enlarged view of a section through the three layers of the ovule. A is the matrix, B the palisade layer, and at D are seen young cotton fibres having their origin in the second layer of cells beneath the cuticule, forcing themselves up through it. C is the starch layer, which contains a store of nutriment to nourish the matrix and embryo.

Fig. 28 is a view of a similar section taken when further growth has occurred, and in which the rounded form of the fibre, as it elongates from the natal cell, begins to assume a ribbon-like structure which is afterwards accentuated by the pressure of the fibres upon each other, when they become more numerous and form a tangled plexus or covering over the whole surface of the cuticle.

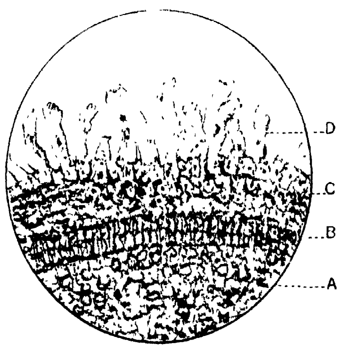


Fig. 28.—Section of Outer Layer of Cotton Ovule. × 75 diameters.

A. Starch cells. C. Cotton matrix.
B. Palisade layer. D. Young cotton fibres, showing nucleus of cell.

In some of the fibres the nucleus of the cell out of which it is generated appears for some time until it is absorbed.

The microscopic study of the fibre at this and succeeding stages leaves no doubt that it is composed of a single elongated cell, which is continuous throughout its whole length; and this continuity of the cell-wall gives the fibre a uniformity of strength which would be wanting if it was developed out of a succession of cells, by the absorption of the cell-walls at the point of junction, which would

necessarily leave a weak link at each of these places. This is one reason why cotton forms an almost ideal fibre for textile purposes, because it is capable of almost equal flexure in every direction throughout its entire length without great diminution of tensile strength, and its suppleness enables it to be twisted and turned, or even knotted without fracture of the cell-wall.

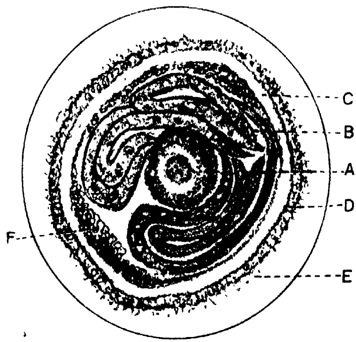


FIG. 29.—Section of Ripe Cotton Ovule. × 30 diameters.

A. Hypocotyl.
B. Cotyledons.
C. Palisade layer.
D. Cotton matrix.
E. Cotton fibres.
F. Starch cells.

While these changes are occurring in the outer or parenchymatous layer, the inner starchy layer is also undergoing most important modifications, resulting in the development of the various parts of the embryo and the gradual absorption of the cell-contents of this envelope. The process of this change seems to consist in the formation of a denser portion of the nucellus into a cell-cluster, which receives the generative cells from the pollen tubes, each of which contains a sperm nucleus; and from the

union of these cells the generative action commences until it spreads throughout the whole of the nucellus, and the nutritive starchy sac, within which, when the development and differentiation is complete, the various parts of the rudimentary plant in its cotyledonous stage are clearly

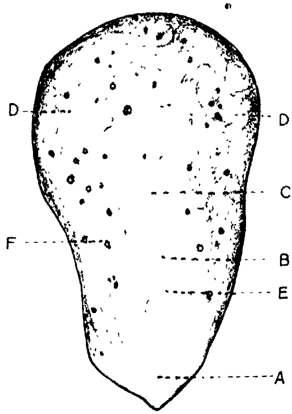


FIG. 30.—Longitudinal Section of Cotton Seed. × 7 diameters.

A. Root area. D. Embryo cotyledons.
B. Primary stem or hypocotyl. E. Root germ.
C. Primary axis. F. Oil canals.

seen, especially when the structural differences are brought out by the use of stains.

In Fig. 29 a diagrammatic section of a ripe ovule is figured. A represents the hypocotyl with its cellular centre; B the interfolded cotyledons with their oil tubes; C the consolidated and pigmented palisade layer now forming the pericarp; D the cotton matrix, now almost completely absorbed; and covered only by the smallest fibres E, as the whole of the lint has been removed;

F shows the last remains of the empty starch and nutrient cells still adherent to the inner wall of the pericarp.

Fig. 30 shows a longitudinal section of a ripe seed at the same stage of growth, with the lint removed, so as to facilitate the section, and although the parts are not so clear the various organs are still quite easily seen. A is the root area from which the sprouting first begins when

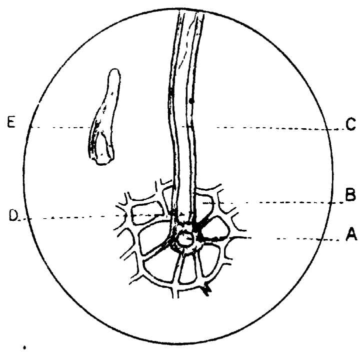


FIG. 31. Unicellular Fibre. × 200 diameters.

A. Root nucleus of fibre. C. Fibre.
B. Cells. D. Endochrome.
E. Point of fibre showing solid end.

the seed is planted, and the origin from which the rootlet is derived, and this nucleus can be seen at E. B is the primary stem, C the primary axis, and D sections of the embryo cotyledons with their oil ducts.

Young cotton fibres taken at this stage, just before the capsule or seed pod bursts, and cut in horizontal section, present a circular or oval form near to the point of origin, and higher up that of a flattened oval cell with a cavity or lumen in the centre and somewhat thickened edges.

When highly magnified, there is no appearance of any structure whatever in any part, and even polarised light fails to reveal any want of uniform homogeneity in the cell-contents. If highly magnified and examined in vertical section the method of attachment to the matrix can be clearly seen; and in Strasburger's *Text-book of Botany* he figures one of these hairs which is reproduced in Fig. 31. At this period in the history of the cotton fibre, when

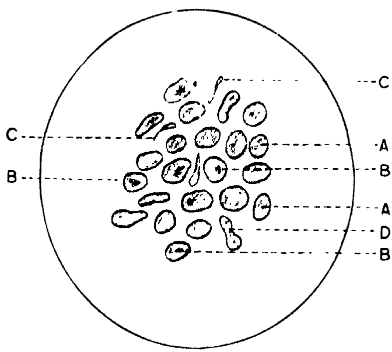


FIG. 32.—Section of Young Cotton Fibres. × 100 diameters.

A. Round or oval section. C. Ribbon-like section.
B. Cells showing nuclei. D. Section of collapsed cell.

they are enclosed within the carpel, they show, when magnified, no evidence whatever of any kind of structure; as the thin pellicle which forms the outer sheath of the hair is so attenuated in most cases as to show in section only a faint circle with well-defined outline, only when the section is made near to the point of origin, and more or less oval, and in some cases reduced almost to a single line in some parts, which would correspond to a section of one of the small ribbon-like hairs.

Fig. 32 shows some of these young fibres in section taken from various parts of the hair. At A are seen the rounded and oval form of cells, with well-defined outline, before any beginning of secondary deposits on the inner surface of the pellicle. D shows similar structural forms, but containing a nucleus situated in different positions within the fibre walls. C represents some of the collapsed

FIG. 33.—Cotton Pod. Natural Size.

fibres where there is only a well-defined wall at one extremity, tapering off to a thickness apparently only the width of the outer pellicle itself, and at D there is a fibre which shows a section like a collapsed tube.

The Cotton Pod.—While these changes are taking place within the ovary there is also a considerable change occurring, which is visible without the aid of the microscope to the naked eye, in the form of the seed-pod which remains on the stalk after the flower has perished.

As soon as the full maturity of the flower is reached and the ovules have been fertilised, the flower, by a curious movement, twists the petals and stamens off, and there remains a pod or boll which is supported by the triangular-shaped deeply imbricated calyx. This continues to increase and swell until it reaches the size of a small bird's egg or a large filbert. At first the colour of this pod is green, but as it gradually ripens the colour changes into brown; and at the same time the surface which was soft becomes hard and rigid, with ridges running from the point down towards the point of attachment, with a groove down the centre of the ridge, which indicates the line along which the seed-pod will open when the pod bursts.

Fig. 33 is sketched from a pod just before the capsule commences to open, and it will be seen enclosed in the calyx which is thrown back where the pod opens.

Fig. 34 shows the gradual development of a cotton pod, after the calyx is removed, from the earliest complete appearance of the bud to full ripeness, and when the pod has burst open by the pressure of the growing fibres between the surface of the seed and the inner walls of the pod.

The time taken during the period of development was noted, and was as follows:—

1. 10 days after the fall of the flower.
2. 20 ,, ,, ,,
3. 30 ,, ,, ,,
4. 40 ,, ,, ,,
5. 60 ,, ,, ,,

This corresponds roughly with the time usually taken by cotton grown in the open.

Bud 1 was quite green, but gradually changed, and the

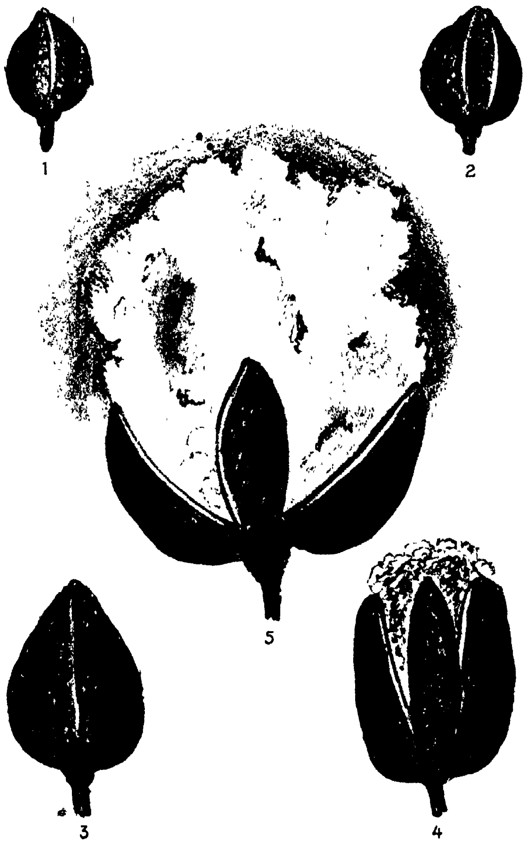


Fig. 34.—Cotton Boll. Natural size.

carpel became dark brown, and very hard at the time of opening.

In the earliest stages the cotton fibres, as shown in Fig. 32, have a more or less rounded form, the walls of the cell being regularly expanded in every direction by the fulness of the protoplasm enclosed within it; but as the fibre grows and is pushed out into the space between the seed surface and the capsule, and subjected to the pressure of the surrounding fibres, it loses this circular section, and becomes more or less flattened, and just before the bud bursts the outer walls of the cells have become so attenuated in the longest fibres as to be almost invisible even under high microscopic power, and present the appearance of a thin pellucid ribbon or band, without any traces whatever of structure of any kind, except a slight wrinkling of the surface, and in some cases a waviness occasioned by the fibre being crumpled up by contact with the surfaces of other fibres.

As soon as the pod opens the imprisoned fibrous mass expands, and swells out into a large fluffy ball of apparently tangled fibres, in which it is exceedingly difficult, if not altogether impossible, to separate the fibres which have their attachment to any particular seed from each other, the whole forming a feathery mass of more or less irregular manner arising from their displacement from their regular position by the unequal pressure of this expansion.

While this mechanical change is occurring the effect of it, as described above, is seen in 5 of Fig. 34. When the parts of the seed-pod are turned back the naked points of some of the seeds are seen as black patches in the midst of the white fibres. There is also another action taking place as a consequence of the opening of the pod.

The Ripening of the Fibre.—The admission of air,

and the action of sunlight, cause a gradual unfolding of the hairy plexus and a drying up of the moisture which surrounded the fibres while within the pod; and the same action also occasions the cell-contents to undergo a chemical change, which corresponds to the ripening of fruit. In the earliest period of their formation the growing cells are filled with juices which are more or less astringent in character, which can readily be tested by applying the tongue to the juices which flow out of the cells when a young pod is cut in section. As the fibre ripens these juices are replaced by more or less neutral fluids, which gradually change and dry up, until in the perfectly ripe fibre the cell-wall is composed almost entirely of a substance—one of the carbohydrates closely allied to starch, and called cellulose—which is one of the most neutral of all chemical bodies, and which will be considered later on. Mixed along with this there is also a quantity of mineral matter which seems to be necessary for every organism, as it is always present in more or less proportion in all organic substances.

When the cotton boll is fully ripe the cotton fibre has reached its point of maturity, and it is in this form that it becomes useful for textile purposes.

If a fibre is selected and placed under the microscope and examined by reflected light, the whole surface seems to be covered with transverse and longitudinal creases. So much is this the case that they appear to be corrugated in the direction of their length, but the corrugations are seldom continuous, and very frequently broken by ridges in the transverse direction formed by a wrinkling up of the surface. In others the surface seems to be more or less cracked all over in very irregular patches, as though the shrinking and collapsing of the fibre had been accompanied by an actual rending of the external layer or sheath. This

appearance is most frequently observed when the fibre presents the least appearance of tubular structure, when seen under transmitted light, as though, if it ever possessed a tubular structure at all, it was so thin in the tube-wall, that it was capable of a complete collapse at the edge as well as in the centre. In samples of fibre taken before maturity is reached the appearance, when viewed under reflected light, is like a tangled plexus of silver rods or

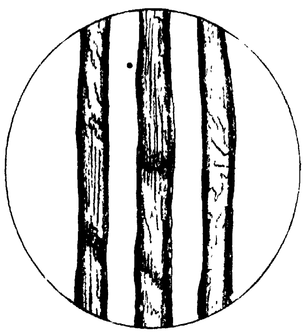


FIG. 35.—Young Cotton Fibres (seen by reflected light). × 250 diameters.

twigs, with more or less similar markings formed by the folds of the plastic cell-walls, with their waxy sheath, and exhibiting little sign of the twistings which are the peculiar characteristic of the fibre in its later stage when in a drier and more inspissated condition. Fig. 35 shows a few of these fibres taken from the pod after opening and before any drying has occurred; and when stretched under the microscope they present an appearance almost like a silk fibre in which no cellular structure appears and no twist, but the fluting and cross-marking are clearly seen.

If transmitted light is used when the fibre has reached maturity an entirely different appearance is immediately presented. The surface-markings become almost invisible when compared with the complicated structure which is revealed within the tubular walls, and which is quite visible through the transparent pellicle which forms the outward sheath or envelope of the fibre. Indeed, the transparency of the whole fibre is so great that, except in certain cases in which there appears a slight endochrome or colouring matter in the cell-contents, the plexus of lines, occasioned by the dark shades of the creases on the two surfaces, renders it very difficult to make out the nature of the internal structure, without subjecting the fibre to some process which will colour the interior cell-walls, and thus enable their structural peculiarities to be observed. So great is the diversity in nature that it may truly be said that each fibre has a structure of its own, and differs in many particulars from all its fellows.

A perfect and typical cotton fibre would, when fully matured, consist of four parts.

1. An outer cuticle or integument which is perfectly continuous, and which forms the skin or sheath of the fibre.

2. An inner tube or layer of more or less homogeneity attached to the inner surface of the outer layer, and formed by successive deposits of cellulose and coagulated protoplasm and other cell-contents, and which forms the substance of the fibre.

3. An inner layer attached to the interior of the secondary deposit, and which seems to be of a firmer consistency, and frequently exhibits indications of spiral structure, specially in wild cotton, and when treated with reagents.

4. A pith-like deposit, containing any endochrome which

may be present in the fibre, and more or less filling up the central cavity or lumen or simply existing in detached and not continuous pieces.

The bulk of the fibres on any seed do not, as a rule, exhibit all these features, but they may also all be present. Such a fibre, if it also possessed the necessary length and diameter, would be perfect for manufacturing purposes.

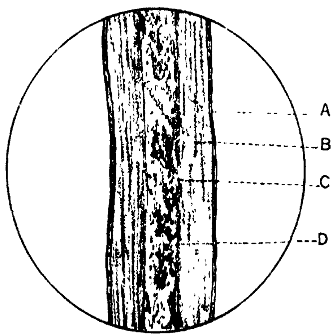


FIG. 36.—Section of Typical Cotton Fibre. × 100 diameters.

A. Outer sheath or pellicle.
B. Secondary deposit of cellulose.
C. Denser layer, sometimes spiral.
D. Tube or lumen with pith-like deposit and endochrome.

Fig. 36 is a diagrammatic longitudinal section of such a fibre when the parts are easily distinguished. A the outer sheath or pellicle, B the secondary deposit, C the denser inner layer, D the endochrome and pith-like material in the central cavity.

It is a matter of considerable difficulty to determine the exact method in which the second and third layers are deposited, so that the tube-wall becomes thicker in the ripe fibre, because, previous to the bursting of the pod, the

cotton fibres, as already noticed, present themselves as thin, transparent, translucent ribbons without the least indication of any well-defined tube-wall. It is not until they are exposed to the sun and air, that the swelling and thickening up of the thin outer sheath or pellicle, which forms the external layer, takes place.

It was formerly supposed that there was a variation in the method in which this occurred in the cotton fibre from that which is the general rule in vegetable cells, and which consists in the formation of secondary deposits within the liber-walls which constitute the exterior envelope.

This appeared all the more probable, because there was an apparently entire absence in the cultivated cotton of any of those special forms of deposit which confer rigidity and strength upon the cell-wall, and which, it seemed, judging from analogy, would have been present more or less in such an elongated cell as a cotton fibre. These special characters generally present themselves under two different types, according to the extent to which they cover the primary membrane. In one case they are applied as a general layer over the cell-wall, absent merely at dot-like or slit-like points, when they do not cover the membrane, and thus give rise to a pitted structure sometimes appearing even as reticulated. In the other case the secondary deposits are more sparing in quantity, and are applied over lines which form a definite pattern upon the liber-walls, and which generally assume a spiral form in the direction of the major axis of the cell, and occurring frequently in both directions, that is, both right and left handed.

Although without previous treatment with various reagents, the fibres of cultivated cotton do not show any

indications of such spiral structure, yet when the cotton has been treated with Schweitzer's reagent, the author was able to detect a distinct spiral tendency in the fibres obtained from some specimens of Austrian gun-cotton kindly supplied by Baron Von Lenk, and which, of course, had previously been treated in the manufacture of the gun-cotton with a mixture of nitric and sulphuric acids. Mr. Higgin of Liverpool also lent a very fine collection of mounted

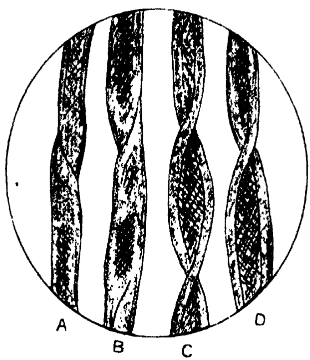


FIG. 37.—Cotton Fibres showing Spiral Structure. × 175 diameters. A and B. Wild African cotton. C and D. Rough Peruvian.

specimens of cotton fibre which were collected by him some years ago, and which ranged from the wild cotton of Africa to the finest Edisto Sea Island cotton. The result of the examination of these specimens leaves no doubt whatever that spiral deposits of the cellulose within the fibre are often present, as they were distinctly visible in samples of the wild African fibres and also in rough Peruvian. Sketches of these appearances are given in Fig. 37, where the more robust and less flexible forms of

the wild African cotton are seen to have distinctly spiral cell-walls at A and B, and the same in the coarse Peruvian at C and D. The fibres of the wild cotton exhibit the appearance of large and weak tubes when compared with cultivated specimens, and while they are somewhat curved, and possess traces of joints or nodes at irregular intervals, their rigidity and inflexibility render them unfit for manufacturing purposes. The occurrence of the spiral

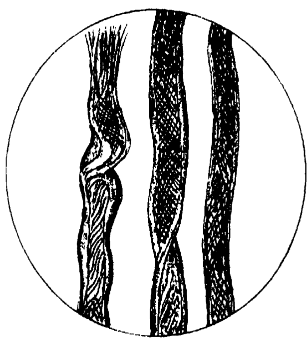


FIG. 38.—Fibres showing Spiral Structure. × 175 diameters.

structure in the rough Peruvian probably supplies us with a case of reversion, a tendency which all plants, when under domestication, often exhibit when more or less neglected in cultivation, to return to the original form in one or more of its characteristics.

Professor Höhnel also, in his work on the microscopical study of fibres, gives an illustration, shown in Fig. 38, of some fibres taken from Swedish filter-paper, which not only shows clearly the spiral structure of the secondary layers, but also these spiral deposits as long continuous

threads, which become straightened when the outer sheath is dissolved and the inner deposit liberated.

In 1863 a series of experiments with a view to determining the structure of the layers which compose the cotton fibre, were made by Mr. Charles O'Neil of Manchester,[1] who treated the fibre with Schweitzer's solution, an ammoniacal solution of oxide of copper, which possesses the power of dissolving cellulose without decomposing it. Writing on this subject he says: "I believed that in the cotton hair I could discern four different parts—The outside membrane which did not dissolve in copper solution. Second, the real cellulose layer beneath which dissolved, but first swelling out and dilating the outside membrane enormously. Third, special fibres, apparently situated in or close to the outside membrane and not readily soluble in the copper liquid. These were not so elastic as the outside membrane, and acted as strictures upon it, producing bead-like swellings of a most interesting character, and, fourthly, an insoluble matter, occupying the core of the cotton hair, and which resembled very much the shrivelled matter in the interior of quills prepared for making pens.

"It is interesting to note that the outside membrane, which was insoluble in the copper oxide solution and impermeable to it, could not be found on cotton, which had been submitted to the treatment of the usual bleaching process; it had either been dissolved away, or, what seems most probable, some protecting resinous varnish had been removed and then it became soluble. The same general results were obtained by acting upon cotton with sulphuric acid and chloride of zinc, and by acting upon gun-cotton

[1] *Calico-Printing, Bleaching, and Dyeing*, by Charles O'Neil, F.C.S., vol. ii. p. 2.

with ether and alcohol. Mr. Dancer of Manchester, an experienced microscopist, repeated these experiments some time after, and he saw all that I described, but considers that the spirals seen did not exist in the cotton hair, but were formed by the twisting or rotation of the hair under the action of the solvent."

In repeating these experiments it was found by the

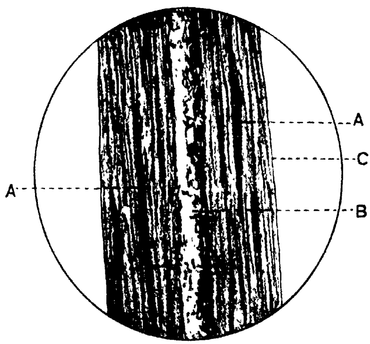


FIG. 39.—Cotton Fibre showing separation of Cellulose Layer. × 1200 diameters.

A. Separation of layers. B. Lumen with pith-like deposit. C. Outer pellicle or sheath.

author that the appearances varied with the nature of the cotton examined, and the degree of maturity which the fibre had attained. In the thin pellucid hairs, where the ribbon-like structure pertained, most of them were dissolved without showing any indication of structure whatever, but they coiled up and wriggled about under the influence of the solvent, almost looking as if they were alive. The more mature and distinctly tubular fibres swelled out, something in the same way as when treated with alkali

by the mercerising process (of which mention will be made later on), and then dissolved, but without exhibiting any traces of cell-contents; but in the fully matured fibres which were more opaque, a distinct separation into layers was visible, and a coagulation of the inner contents of the lumen, which was not unlike the "pith" described by Mr. O'Neil. An illustration of this distinct separation of the inner deposit into layers or successive envelopes is given in Fig. 39, seen under high magnification.

Here the solution used was very weak, and the examination was made before the swelling of the cellulose layers ruptured the outer pellicle. This usually occurred at irregular intervals along the length of the fibre, and as soon as the rupture occurred the protrusion of the cellulose rolled up the ring of pellicle until it formed a tight ligature round the swelled material which constitutes the fibre and constricted that part, holding it until the ring was dissolved or disintegrated or gave way under the increasing pressure, and then the cellulose gradually dissolved and left only granular and stringy-looking materials, which seemed to resist the action of the solvent. These appearances are seen in Fig. 40.

In treating the fractured end of a rough Peruvian fibre, where the inner layers of cellulose were drawn out from the outer layer, there was a distinct separation into fibrous bands, which resisted the action of the solvent longer than the enclosing layers, and in some even an indication of a double spiral structure; but no power at command even up to 10,000 diameters, and no reagent revealed a cellular structure either in the cellulose layer in which these spiral fibres were imbedded, or in the outer sheath or pellicle in which the whole fibre was enswathed. It seemed also that the twisting and rotation of the fibre,

when under the action of the solvent, was not the cause but the result of the spiral fibres uncoiling themselves when the cellulose layer, in which they were imbedded, and which was more readily soluble, was dissolving away.

The author was anxious, if possible, to resolve the cellulose membrane into constituent cells, so as to detect,

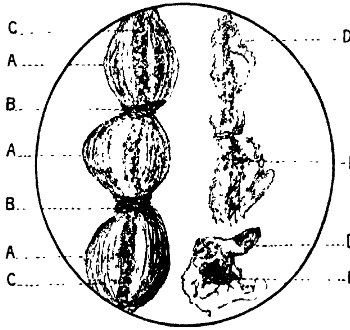


FIG. 40.—Cotton Fibre treated with Cuprammonium Solution. × 200 diameters.

A. Swollen cellulose layers. C. Lumen with pith-like deposits.
B. Cuticular ligatures. D. Undissolved pellicle or cuticle.
E. Undissolved cell-contents.

if possible, the mechanical cause of the separation of the constituent layers, but this was quite impossible, also to detect any structure in the outer pellicle, but this was equally unsuccessful; and there is, therefore, no reasonable doubt that, notwithstanding its great length, it is one continuous membrane, and that those beneath it and in which any spiral fibres are imbedded, are similarly constituted. H. de Mosenthal (*Journal Soc. Chem. Ind.*, March 1904) asserts that the cuticular wall of the fibre is pierced by minute stomata leading into the lumen of

the fibre, and thinks that these offer an explanation of the way moisture, and with it tinctorial reagents, penetrate the interior of the cell. These fibres also, as exhibited at the end of the rough Peruvian cotton, could not be resolved into constituent parts. In the common cotton sedge (*Eriophorum polystachyum*), which is not, however, a true cotton, the division of the cells is quite distinct, and it is quite possible that this might also be seen, if looked for, in the coarsest fibres of wild cotton growing in its native habitat.

Classification of Fibres.—Generally all the fibres found on the seed may be divided into four distinct classes, which, however, shade into each other.

1. Short, stumpy, stiff fibres which are usually found near the growing point of the seed, and which are the last to develop on the pod, and may be termed basial.

2. Immature or unripe fibres, where no internal structure is visible.

3. Those in which the structure is simply tubular, with a distinct internal cavity or lumen, and well-defined transparent walls, and exhibiting the characteristic fibrous twist.

4. Fibres where the structure is tubular, and the interior of the cell-wall filled with secondary deposits which almost entirely fill up the internal cavity, giving the fibre a dense, almost opaque appearance, and exhibiting the characteristic twist in a marked degree.

There are various degrees of distinctness in which these characteristics are manifested in different filaments, and many more divisions might be made, dependent on the length, thickness, and number of twists present in the fibre in a given length; but for practical purposes these divisions are sufficient to cover all the differences which usually appear in cultivated cotton.

1. The short fibres, which form an undergrowth to the longer ones, and which are not removable by the ginning process because too short to be caught either by saws, knives, or rollers, are of little service in manufacture, and often a cause of considerable annoyance, when the seed is broken up in the ginning and small tufts of these hairs are then carried along with the lint and require to be entirely removed, or otherwise they form neps and do not receive

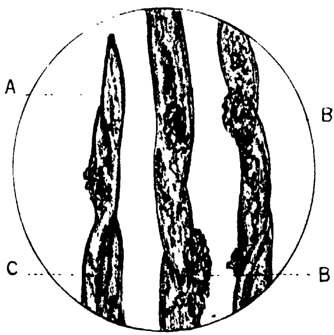


FIG. 41.—Short Basial Cotton Fibres (Fuzzy Fibres). × 150 diameters.

A. Solid apex of fibre. B. Resinous oily deposit.
C. Cavity or lumen.

The ι.

varieties orthe same way as the longer fibres. Recently, slight tinctor use has been found for them in the making however, never nd other absorbent paper. After they are standard of colour wh₁seed by a special machine, they are formed and matured fibres as to remove the gummy matter that in all bolls of cotton somtys associated, and which on full maturity from one cause or anos, an exudation of this position on the matrix prevents their geof the seed. When of light or nourishment, or they have lan absorbent than

any other cotton fibre, as they are more loose in texture. Fig. 41 shows the structure of these fibres and adhering resin.

2. The second class of fibres occur most frequently in early and unripe cotton, and often also in cotton which is over-ripe or has been left on the tree for some length of time after the full maturity of the opening of the boll has been attained. In both these cases the outer sheath of the fibre appears to be of extreme tenuity. In one case this arises from the fact that from some cause or other the fibre has been detached from the seed before the period, when the filling up of the interior lumen has commenced and the other probably by the process of re-absorption, which always sets in when any organic structure has reached maturity, and which gradually, while it may give an increased density to the outer cell-wall, materially decreases its thickness.

There is also another form in which this want of internal structure is observed, and which is of peculiar interest to the technologist, by the tendency which some of the fibres appear to have to form in certain portions of their length in a solid, non-porous state, which, while it seems quite homogeneous and transparent, is quite incap- most of the permeation of dyeing or other tinctorial mat- dense, any of the ordinary processes which will inject -acteristic portions of the fibre. This is analogous to the of "kemps," in wool, where the fibre become- in which these like texture, quite smooth, and poss- -ferent filaments, and surface scales, upon which the f- made, dependent on the depends. In the cotton fib- -er of twists present in the usually found for a sh- -th; but for practical purposes these fibre which forms -ent to cover all the differences which characterised by -cultivated cotton.

mechanical processes to which cotton is subjected in the process of manufacture, this part probably breaks off, for it is very seldom found after the cotton is in the yarn. This solid formation is seen at E in Fig. 31. In the body of the fibre this structure is very seldom found, except in the coarser qualities, such as rough grades of Surat or Peruvian, but it frequently occurs in wild cotton. It never occurs in Sea Island or in Egyptian cotton.

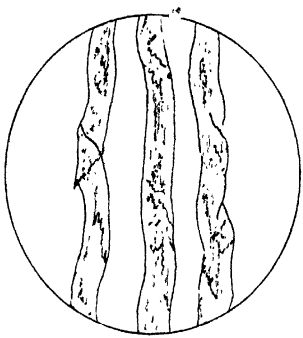


FIG. 42.—Dead or Unripe Cotton Fibres. × 200 diameters.

The thin ribbon-like structureless fibres occur in all varieties of cotton, and they are capable of receiving a slight tinctorial tinge under the action of dyes, which, however, never seem able to bring them up to the full standard of colour which can be attained in the perfectly formed and matured fibres. The probability is, therefore, that in all bolls of cotton some of the fibres never attain full maturity from one cause or another. Either their position on the matrix prevents their getting a sufficiency of light or nourishment, or they have lacked vigour of

growth; and the proportion of such fibre to be found in cotton probably depends also upon the character of the season and the general health of the plant. These fibres also are always deficient in strength, and break up in the manufacturing process, and are a source of loss as increasing the proportion of waste which is made, and weakness in the yarn or cloth. Fig. 42 shows the appearance of this fibre when seen with transmitted light.

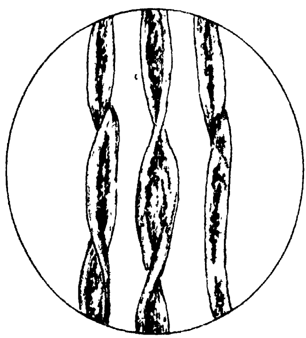


FIG. 43.—Half Ripe Cotton Fibres. × 200 diameters.

3. This class of fibre exhibits a distinct tubular structure, in which the cell-walls are well defined, but where they differ in the strength of the wall from a thin structureless condition little removed from the unripe fibres to a solid, well-defined robust fibre, which stands closely related to the fourth class. Fig. 43 represents these fibres.

4. These fully mature fibres differ only in degree from the typical cotton fibre which possesses all the best characteristics of a spinning cotton, and which are the same as those defined for good textile fibre, and enumerated

on page 6, Chap. I. These fibres possess the power of permitting various dyeing materials to pass through into the interior of the tube-walls, where in some cases they are retained in dense crystalline masses. When acted upon in this way by various chemical reagents the rigidity and solidity of the cell-walls appear to be increased, and in many cases the thickness also.

It seems as if in this fully matured fibre the central

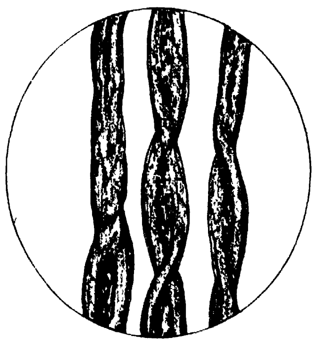


FIG. 44.—Fully Ripe Cotton Fibres. × 200 diameters.

opening, up which the sap passed during the period of growth, had been fully or almost entirely filled up, when the full length of the fibre was reached, and the vital action, which supplied the cell-contents, actually arrested; and while the interior deposits are fully matured, they are shrunk in towards the denser walls which form the outer pellicle, but without losing their structure, so that they are ready to be expanded again inwards when their interior is filled with either fluid or solid contents as the case may be. These fibres are seen in Fig. 44.

Twist in the Fibre.—This peculiarity, which is so marked in cotton, is not generally possessed by vegetable fibres. The true hairs are usually quite smooth, and show little signs of any form of twist. This is very marked in what is called vegetable down or bombax cotton, which is not a true cotton and not derived from the Gossypeum family, but from the Bombaceæ; and the origin of the fibre is also different, as it grows not from the surface of the seed but from the inner lining of the capsule. This cannot be made to twist, and although having a high surface lustre cannot be used for textile purposes, and has little strength. The same may be said of the beautiful thistle-down, which exceeds silk in lustre, but cannot be spun; and also of the Asclepias cotton, or common silk-weed or milk-weed, which grows extensively in America, and although used along with cotton, is too brittle and easily breaks up, especially when dry, and falls out from the combination.

This peculiar characteristic twist, which is so marked in cultivated cotton, and which gives to it the necessary quality which enables it to be spun into a thread, which is impossible in the wild fibre, is not possessed by the fibre in its early stages, or indeed, until it has been subjected to air and sunlight. The fibres taken from an unopened pod have no twist. They are always moist from imprisonment within the seed capsule, which is saturated with sappy juices and mucilage, and there is no tendency to desiccation on the part of the fibre unless it is placed in a dry position. The twist only appears after the fibre, which reaches its full length in the boll, or almost so, is exposed to desiccation. The twists are not a complete convolution, or revolution of the fibre on its central axis, but are sometimes in one direction, and then in another, even in the

same fibre. This twist is put in in the most unequal manner, and presents all kinds of variation,—long twists, and short twists, and partial twists, and then lengths without twist. There does not appear to be any doubt what the cause of it is; the parts of which the fibre is composed differ in structure and density. The thick wall formed by the secondary deposits upon the inner surface of the pellicle is not so dense as the inner lining on its own interior surface. In addition to this the thickness of the secondary deposit is not equal throughout, and as there is every reason to believe that this deposit is also spirally arranged, as is clearly seen in wild cotton, and also frequently in the cultivated fibre when treated with solvents, which permit the unequal strain arising from this to exert itself and cause a twisting action, the drying up will always take place first in that part of the fibre where the deposit is the least in thickness, and as the outer pellicle contracts it exerts a lateral strain on the wall of the fibre, which is held by the denser deposit within and tends to twist it round the central axis as the tube-wall collapses. This, in turn, when the tube has been twisted several times in one direction, makes it increasingly difficult, as the number of twists in that direction take place, to continue the twist in the same direction, and so when the lateral strain comes on another part of the drying fibre it is easier for the twist to reverse, and so the twists are seldom more than five or six in one direction, before a reverse twist takes place, and often only two or three. It must also be remembered that the twists do not occur at different times, but the desiccation is occurring in all parts of the fibre at the same time, and the twisting action starts from many points at once, although in many cases, and specially on those parts of the boll where it is exposed

to the full heat of the sun, it commences first at the top of the fibre. The number of these twists per inch is very variable, not only in different classes of cotton, but even in the fibres on the same seed, and depends on purely local conditions, but the tendency of cultivation is to increase them, and they vary from only one or two hundred up to as many as over three hundred, and are more numerous in fine than in coarser cotton. In some cases for a considerable distance it seems as if the fibre had been entirely twisted round the central axis, but these cases are very rare. The position of any fibre in the boll, held as it is, entangled amongst the other fibres, renders it quite impossible that any complete rotation of the fibre could possibly occur, and this is also proved by the reversion of the twist at intervals. The reason why the twists are never so numerous in the fully ripe fibres of coarse cotton is because the fibres are more rigid in consequence of the firmness and thickness of the secondary deposits than in the finer and longer staples, which cannot resist torsion so well. Hence we have the most numerous twists in the finest cotton. The following table gives an approximate estimate of the number of twists per inch in various classes of cotton, but these are found to differ very considerably in fibres even from the same boll :—

NUMBER OF CONVOLUTIONS IN COTTON FIBRE

	No. Tested.	Maximum.	Minimum.	Mean.
Sea Island . .	50	360	240	300
Egyptian . .	50	280	175	228
Brazilian . .	50	260	158	210
American (Orleans) .	50	240	144	192
Indian (Surat) .	50	190	120	150

These were taken in one year in which the cotton was all of good quality, and represent the twists in both directions, as it was impossible to distinguish between them. It may be noticed that this reversion in twist is an additional advantage in cotton-spinning, because it increases the locking action of the fibres when the twist is put in, as they are analogous to the holding power of a combined

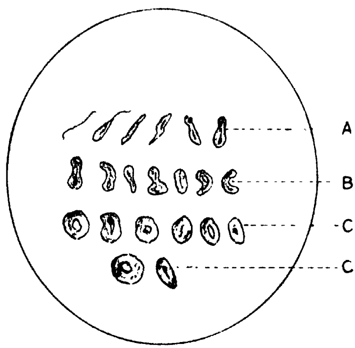


FIG. 45.—Sections of Cotton Fibres. × 200 diameters.
A. Immature or dead fibres. B. Half ripe fibres.
C. Fully ripe fibres.

right- and left-handed screw, and so hold in whichever direction the torsion comes.

Cross-sections, through the various parts of the mature cotton, as growing upon the various positions on the seed, exhibit almost every variety of form corresponding to the different states of growth, from a thin pellucid line to the full robust fibre with thick cell-walls, and in some, with high magnifying power, all the various parts as exhibited in Fig. 36, can be faintly seen.

In Fig. 45 an illustration of such sections is given in

which the various classes are seen exhibiting the distinct differences. At A are seen the thin ribbon-like line and variations in the thickness until they shade into B, which represents the half ripe, or arrested-development stage, in which the collapse of the tube-walls is quite distinct, sometimes filling up the centre cavity. C C show the fully ripe fibres with strong well-developed walls and the secondary deposits, almost and in some cases completely filling up the whole of the interior of the fibre. Also the greater density of the innermost lining. This denser layer, which plays such an important part in the twisting of the fibre, may either be a special third layer, or may arise from the shrinking in of the second layer, and also from being formed from the last remains of the protoplasm which is probably thicker or more inspissated as the progress of the deposition of the layer continues.

The sections of all classes of cotton are very similar in appearance, only larger in diameter in the coarser kinds; and it may be noticed that it is the shorter cottons which exhibit the greatest and most robust sections, and these seem, on the average, to be inversely proportional to their length, so that although the diameter is so much smaller in a Sea Island or Egyptian fibre than in a Surat of coarse Peruvian fibre, the total area of the interior of the central cavity or lumen is roughly similar, and will hold the same amount of secondary deposit, although in the coarse fibre it is thicker on the walls, and in the other deposited over a larger area. This also accounts for the difference in breaking strain, as will be seen hereafter, and also for the small difference in the weight of each fibre, as they, on the average, when fully ripe, contain the same amount of material, the length of one making up for the thickness of the other. A number of fibres of good American

cotton were carefully counted and weighed on a delicate chemical balance, and it was found that, based on this weighing, from 14,000 to 20,000 fibres only weighed one grain, so that it required 140,000,000 for every pound, and each hair only weighs on the average $\frac{1}{17,000}$th part of a grain. Taking the average length of an American cotton fibre, if they were placed end to end, they would reach about 2200 miles.

Diameter and Length of Cotton.—Cotton grown in different parts of the world differs considerably in the length and fineness of the staple, as it is termed, the long Sea Island cotton grown on the shores and islands of the coast of Florida and Georgia attaining a length of nearly two inches, while the short native cotton of India scarcely exceeds $\frac{3}{4}$ of an inch.

The district, however, does not seem to affect the length of the staple so much as the character of the seed from which it is grown, as Sea Island cotton seed has in India produced a fibre little shorter in staple than when grown in its native habitat, although probably, if grown for a number of years without fresh seed, it might alter in this respect as a result of climate and environment. The following table, taken from Evan Leigh's *Science of Cotton Spinning*, published about twenty years ago, and now out of date as regards the mechanical part, gives the length and relative fineness of staple in cotton from various localities; it was the result of a large number of measurements taken from fully ripe fibres and corresponds very closely to the measurements taken quite recently.

They can only, however, be taken as approximate for any given season, as the average length and diameter vary in different years for the same class of cotton grown in the same district and country. It is also a well-known fact

that from year to year, in any class of cotton, such as American or Egyptian, the degree of abundance of long or short stapled cotton varies considerably, as well as the fineness and general silkiness of the fibres composing it. The cotton crop is like the fruit crop, which from year to year differs both in quality and quantity, the best seasons which favour the crop in every respect producing both in the highest degree.

A considerable number of fibres from the different classes of cotton given in this table have been measured during the past few years, but the results on the average do not differ very widely from those contained in this table.

[TABLE

LENGTH AND DIAMETER OF COTTON FIBRE

Place of Growth.	Description of Cotton.	Length of Staple in Inches and Decimal Fractions				Diameter of Fibre in Decimals of an Inch.			Fractions Mean.
		Min.	Max.	Mean.	Mean.	Min.	Max.	Mean.	
United States .	New Orleans .	0·88	1·16	1·02	$1\frac{1}{50}$	0·00058	0·00097	0·000775	$\frac{1}{1290}$
Sea Islands .	Long Stapled .	1·41	1·80	1·61	$1\frac{6}{10}$	0·00046	0·00082	0·000640	$\frac{1}{1562}$
South America .	Brazilian . .	1·03	1·31	1·17	$1\frac{17}{100}$	0·00062	0·00096	0·000790	$\frac{1}{1265}$
Egypt . .	Egyptian . .	1·30	1·52	1·41	$1\frac{41}{100}$	0·00059	0·00072	0·000655	$\frac{1}{1526}$
	Indigenous or Native . .	0·77	1·02	0·89	$0\frac{89}{100}$	0·000649	0·001040	0·000844	$\frac{1}{1185}$
India . .	American Seed .	0·95	1·21	1·08	$1\frac{2}{25}$	0·000654	0·000996	0·000825	$\frac{1}{1212}$
	Sea Island or Egyptian .	1·36	1·65	1·50	$1\frac{1}{2}$	0·000596	0·000864	0·000730	$\frac{1}{1369}$

Very similar measurements to these were made by Captain J. Mitchell of the Government Central Museum, Madras.

Variation in Length and Diameter.—From this table it will be seen that there is considerable variation both in the length and diameter of fibres of cotton grown in the same district, a difference which arises from a variety of causes, and is influenced also to a larger or smaller extent by the climate which varies from year to year.

As a rule also it will be seen from this table that the longest fibres have the smallest diameter, and are therefore finer and silkier in the staple.

The extreme variation in the length of the staple is as follows:—

America (Orleans)	0·28 of an inch.
Sea Island	0·39 „ „
Brazilian	0·28 „ „
Egyptian	0·22 „ „
Indian (Surat)	0·25 „ „

The extreme variation in the diameter of the individual fibres is:—

	Inch.	Fraction.
American (Orleans)	0·000390	$\frac{1}{2560}$
Sea Island	0·000360	$\frac{1}{2777}$
Brazilian	0·000340	$\frac{1}{2941}$
Egyptian	0·000130	$\frac{1}{7692}$
Indian (Surat)	0·000342	$\frac{1}{2557}$

From this table it appears that Egyptian cotton is the most regular, both in length and diameter of fibre, the greatest difference being $\frac{22}{100}$ths of an inch in length, and $\frac{1}{7692}$nd of an inch in diameter; while Sea Island cotton, although possessing the greatest length and smallest diameter of fibre, exhibits also the greatest variation, viz., $\frac{39}{100}$ths of an inch in length and $\frac{1}{2777}$th of an inch in the diameter of the individual fibres. It will also be seen that the

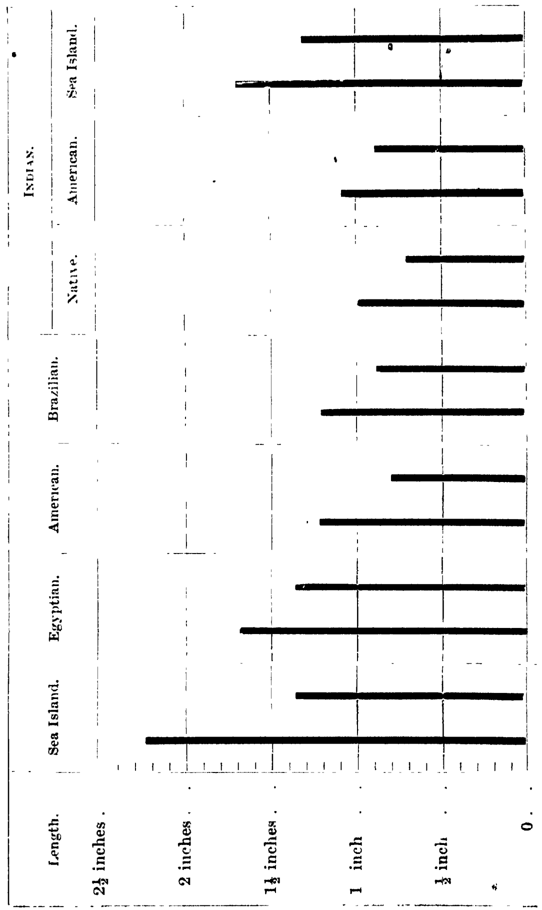
variation in the diameter is proportionally very much larger than the variation in the length; and indeed this peculiarity strikes the eye at once when looking down into the tangled plexus of a lock of cotton placed under a low power within the field of the microscope, and it is a matter of astonishment, considering the variation in the fibres, that yarns can be made so regular and even as they are now produced by the most improved machinery.

The figures given above are not easy to carry in the mind, and especially to persons not accustomed to microscopical measurements, and the relation between the diameter and length may be illustrated by the fact that if an average staple or fibre of good American (Orleans) cotton was magnified until it was one inch in diameter, it would be a little over 100 feet long, and a Sea Island or very fine Egyptian fibre magnified to the same diameter would appear 130 feet long.

Each individual fibre also varies in diameter in different parts of its length, being, however, when fresh from the boll, as a rule pretty uniform, until about three-fourths of its length is reached, when it gradually tapers off at the end farthest from the seed to about one-fifth of its maximum diameter, and ends somewhat abruptly, not unlike the extremity of a worm, as may be seen at E in Fig. 31. The end is sometimes bifurcated, and is usually solid and round in section. Unless taken direct from the boll it is difficult to find a continuous fibre after the ginning process, because the ends are frequently broken off and terminate in a ragged edge. The same remark applies to the root.

The variation in length of the fibre is best seen graphically in the following table, where the length of each kind of fibre is presented in maximum and minimum inches and decimals of an inch.

COMPARATIVE LENGTH OF VARIOUS COTTON FIBRES



American cotton, which forms the greatest portion of the world's supply, has been examined in regard to the average length and maximum and minimum length and diameter, and also in regard to the breaking strength of the fibres and weight of the seeds, State by State, in the United States, by Professor Ordway; and the following table is taken from the United States Tenth Census Report.

AVERAGES OF EACH STATE

Name of State	No. of Samples.	Maximum length (inches)	Minimum length (inches).	Average length (inches).	Diameter in 1000ths of an inch.	Breaking weight in grains.	Weight of five seeds in grains.
Alabama .	60	1·427	0·789	1·027	0·896	137·8	12·38
Arkansas	13	1·143	0·965	1·036	0·917	134·7	13·36
Arizona .	4	1·192	0·745	0·969	0·957	133·7	11·96
California	19	1·669	0·827	1·079	0·921	144·6	12·58
Florida .	45	1·910	0·854	1·384	0·793	124·1	12·64
Georgia .	52	1·572	0·806	1·066	0 913	136·9	12·80
Indian Territory	2	1·140	1·023	1·081	0·905	119·3	13·42
Louisiana	24	1·267	0·862	1·069	0·882	127·5	13·01
Mississippi	18	1·282	0·810	1·047	0·957	134·3	12·11
Missouri .	6	1·260	0·907	1·098	0 890	136·4	12·76
North Carolina	94	1·357	0·695	1·058	0·929	132·7	12·55
South Carolina	26	1·996	0·776	1·234	0·957	120·3	11·80
Tennessee	7	1·131	0·821	0·992	0·898	133·3	12·33
Texas . .	72	1·380	0·819	1·075	0·897	132·8	13·07
Virginia .	8	1·366	0 883	1·060	0·945	126·1	14·00

Since this table was published considerable improvement has been made in the quality of special growths in the United States, and this has been specially the case in some of the Sea Island varieties, and fibres have now been obtained which are above 2¼ inches long.

A careful examination was also made to determine if there was any great variation between the average length

of the fibres before commencing the process of manufacture and after the cotton had passed through the earlier stages in the card-room up to the last head of drawing. This examination was made exclusively with Egyptian cotton, but no difference could, on the average, be established, as it was found that as good staple in length, when measured, could be obtained from the last head of drawing as could be drawn out of the cotton in the mixing, and from this it appears that when the scutching, carding, combing, and drawing are correctly performed no deterioration in this respect occurs. The average diameter of the fibres remained also the same.

The cotton was also carefully examined to see if there was any deterioration or injury to the fibre by breaking or cutting during the carding process, and it was found that when the cards were properly set the fibre was entirely uninjured. When, however, the card was improperly set, and specially in regard to the revolving flats, injury was detected in many fibres, causing increased waste and weakening of the yarn. Excessive speed in the card caused rapid deterioration, probably occasioned by the "snatching" of the fibre in place of gentle lashing and combing by the teeth of the fillet.

CHAPTER VI

CHEMISTRY OF THE COTTON FIBRE

the great laboratory of Nature changes are always irring, both of a mechanical and chemical character, and nost cases these are not separate but concurrent and ltaneous. Living material is always in a state of able equilibrium, building itself up and breaking itself n, and upon these changes the development and conance of the living organism depend.

'he unit of all living organisms, whether vegetable or ial, is the cell, and from this cell, by means of multition and differentiation, all the various parts and ns of both plants and animals are derived.

'egetable cells are always larger than animal cells, are distinguished by being surrounded by firm walls, h mark their boundary and separate them from each r. If an active living cell is observed through the oscope it will usually be found to be, in the vegetable a more or less transparent cubical or tabular cavity sed within a bounding pellicle or membrane, and filled a transparent fluid. In all these cells there will ys be found, and clearly distinguishable, a round body, a delicate membraneous wall, which fills the greater of the interior of the cell. This body is termed the

nucleus, and it is usually surrounded on every side by a number of semi-transparent colourless bodies which are highly refractive, and are called chromatophores or pigment-bearers, because they often contain granular colouring matter. This nucleus with the surrounding chromatophores floats in a transparent granular semi-fluid substance, which fills all the interior of the cell, and is termed the cytoplasm or cell-plasm. In the interior of the nucleus there is also a small round body, with a well-defined globular boundary and having a darker mass in the centre. This is called the nucleolus, and the whole of the cell-contents, including the cytoplasm, chromatophores, nucleus, and nucleolus, form what is termed, as a general name for the whole of the elements or protoplast, which constitutes the living portion of a vegetable cell, Protoplasm.

Strasburger, in 1875, discovered that this nucleus is not only a permanent organ of the cell, but also that certain definite constituents of it are transmitted in unbroken sequence from one cell generation to another, and all recent investigations have shown the supreme importance of the nucleus in directing and controlling the metabolic activities. It seems, indeed, certain that the nucleus is absolutely essential in association with the cytoplasm if the cell is to continue its ordinary vital functions, and manifest those chemical and physical properties upon which its growth and multiplication depend. In some way it appears certain that the nucleus or some constituents of it are the prime movers, or exercise a directional influence on the changes in the association of the chromatophores which make themselves apparent in such characteristics as form, colour, etc., which are manifest in the after development of the ovule of which the cell forms a part, and which give to it its distinctive peculiarities and individuality, and thus

preserve its kind. It may indeed be said that the act of fertilisation by the pollen sperm-nuclei conveyed by the pollen tubes into the ovules, consists not only in the union of male and female cells, but also, as discovered by Hertwig, in the union of the two cell-nuclei, which is an essential part of the process. The result is that as soon as this change is completed no other sperm-nuclei can be received

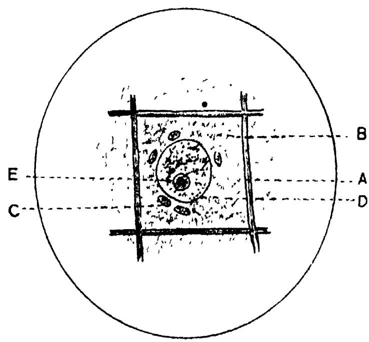


FIG. 46.- Typical Vegetable Cell. × 750 diameters.

A. Cell-wall. C. Chromatophores.
B. Cytoplasm. D. Membrane of nucleus.
E. Nucleolus.

into the cell, and if any succeed in penetrating, they are immediately destroyed by a change which has occurred in the cytoplasmic constituents of the cell.[1]

Fig. 46 is a diagrammatic representation of such a typical cell when magnified about 750 diameters. A is the cell-wall, B the granular cytoplasm, C the chromatophores, D the membrane or pellicle surrounding the nucleus, and E the nucleolus with the dark concentric centre.

[1] *Proc. Royal Society*, Series B, vol. lxxix. pp. 446 and 450.

Protoplasm, which consists of the whole of the protoplast contained within the cell, has been termed the "physical basis of life," because it is never present in anything which has not had life, and always present in living organisms. So far as is known, it is identical in character in both plants and animals. It is the portion of each of these from which the substance of the organism is derived, and its action the cause why they perform their functions. Cellulose is produced from the primary sugar-like carbohydrates. The transformation is effected by the living protoplasts which form a layer of cellulose on their periphery, called the cell-wall. At first this cellulose is deposited chemically pure, and then, according to need, the carbohydrate is changed by the protoplasm, either wholly or in part, into the carbohydrates which have special functions to perform. The protoplasm also forms cellulose at certain points in the interior of its own substance as well as at its periphery, and in addition another carbohydrate called Granulose, and the cellulose and this granulose, often very intimately intermixed, appear in the form of starch grains or Amylum. There is, however, a considerable difference in the relation of the protoplasm to the cell in the plant and animal. In the latter, during life, the cell is always continuously filled with the protoplasm, whereas in the plant-cell the protoplasm soon becomes filled with vacant spaces or areas called vacuoles, and tends to concentrate on the walls of the cell, when it accretes secondary deposits which strengthen the cell-wall, and change their character as this action proceeds into wood fibres, Lignose, and other bodies. It is only in young vegetable cells that the whole of the cell-cavity is completely filled with protoplasm, and in the fully mature cells the cavity becomes entirely emptied of

protoplasm, which is replaced by cell saps in the active cells, and inspissated gummy material in those which form the sustaining and strengthening parts of the plant.

The protoplasm, as distinguished from the formed material which constitutes the stable parts of the plant or animal, is characterised by five attributes, viz.—

1. It possesses, even in the most rudimentary forms of life, the power of motion or irritability which enables it to respond to excitation.

2. It has the faculty of intersusception and assimilation, which enables it to take into its substance suitable material upon which to feed, and to change it into its own substance by digestion. This property is termed Nutrition.

3. It can grow or increase in size, not by accretion on the outside, but by expansion from within.

4. It possesses the power to reproduce its kind either by division or germination.

5. It can excrete from itself other substances which differ in kind and composition, constituting "formed" material.

The cause of these properties is, up to the present time, unknown, but they are always present even in the smallest division which can be made of protoplasm, and they constitute the difference between living and dead matter.

No means are known of investigating its chemical composition while living, as the application of any reagents immediately and permanently arrests these functions, and death ensues. When examined chemically protoplasm yields as the results of analysis—

1. *Water* in varying quantities, but at least 75 per cent of its weight and often more.

2. *Proteids*, which are the most abundant and constant of organised solids. They are substances allied to Albumen,

and are composed of Carbon, Hydrogen, Nitrogen, Oxygen, Sulphur, and Phosphorus in small quantity. The proteids, obtained from the nuclei of the cell rather than from the whole of the protoplast, contain the largest amount of phosphorus, and this substance is called Nuclein.

3. Mineral constituents or ash.

Active protoplasm gives an alkaline and sometimes a neutral reaction, but never an acid one. Like albumen, the protoplasm of the higher plants coagulates at 120° F., and when in a less fluid condition, as in spores and seeds, a considerably higher temperature is necessary, but when coagulation has once occurred death takes place, and there is no possible means of resuscitation.

A certain amount of mineral matter also is always present, but it seems to vary in quantity as well as character with differences in the composition of the soil upon which the plant is grown. Under certain circumstances also the loss of water enables the protoplasm to become less active, and all its properties lie dormant even for years, and on again obtaining a fresh supply of moisture to resume its active condition again. This occurs when seeds are kept for years.

Besides the bodies named above protoplasm always contains, though probably not as an integral part of its substance, derivatives, products of albuminates, particularly amides and also ferments such as diastase; at times alkaloids, and always carbohydrates and fats.

Protoplasm, whether living or dead, is strongly hygroscopic, but the distinction is singularly marked, if any colouring matter is associated with the water. Thus if living protoplasm is treated with carmine it remains unstained so long as it remains alive, but if dead the colouring matter pervades its whole substance, and even concentrates

in it, so that the protoplasm acquires a deeper stain than that visible in the colouring solution. This enables the living protoplasm to be at once differentiated from the formed or excreted material, and so enables the two to be distinguished from each other, which greatly assists in microscopical research.

Protoplasm is a most complicated body, and although many ultimate analyses have been made, it is so far impossible to arrive at any conclusion in regard to the arrangement of the constituents within the molecule.

Function of Protoplasm.—The action of the protoplasm within the growing unicellular fibre of the cotton seed is to assimilate the nutritive material stored within the developing ovule, and to excrete the materials which go to furnish the growth of the fibre and the subsequent deposit of the secondary products on the interior of the fibre wall. The method of deposition has already been considered in the last chapter, and the function of the protoplasm ceases when the fibre has reached maturity, and the cell-contents are entirely absorbed or changed into the substance of the fibre.

As might be anticipated, these formed or excreted materials are not all of one chemical constitution, but consist of a number of substances possessing different qualities, and upon these the composition and chemical reaction of the fibre depend. By far the largest portion of the cotton fibre consists of a substance called Cellulose, of which there are, however, many varieties, so that the term must be taken to represent, unless specially indicated, a group of closely allied bodies rather than a single chemical substance. They are all, however, very stable compounds, being insoluble in all simple solvents, and are non-nitrogenous and belonging to the chemical group known as

carbohydrates, all of which are formed by the union of Carbon, Hydrogen, and Oxygen, according to the empirical formula $C_nH_{2m}O_m$, in which the single bond linking of the carbon atom universally prevails. All their reactions also are indicative of "saturated" compounds.

The researches of Messrs. Cross and Bevan, who are the great authorities on cellulose, have thrown considerable light on the character and reaction of these bodies; and in relation to them they remark, "It must be noted here that the typical celluloses are not separated from the plant in a pure state but in admixture, or in intimate chemical union with other compounds or groups of compounds." The latter are distinguished by greater reactivity, *e.g.* they readily yield to alkaline hydrolysis (pectic bodies), to oxidation (colouring matters), or to the action of the halogens. In the latter is included the very important group of lignified celluloses or lignocelluloses (woods), distinguished by the presence of ketohexene groups in union with the cellulose, and therefore combining directly with the halogens. These points are sufficient to indicate the principles underlying the usual method adopted in the laboratory for the isolation of cellulose from vegetable raw material, which consists in—

1. Alkaline hydrolysis, boiling the tissue or fibres in solutions of the alkaline hydrates (1 to 2 per cent NaOH) and after washing,

2. Exposure to the action of a halogen Chlorine gas (Cl) or Bromine water at the ordinary temperature, and then,

3. A second alkaline hydrolysis, boiling in alkaline solution, *e.g.*, sodium sulphite, carbonate or hydrate, to complete the resolution, and to dissolve away the products formed from the non-cellulose constituents by the preceding treatment.

After such treatment, and thorough washing, the material is treated exhaustively with alcohol and with ether, to remove fatty or resinous by-products of the oxidation.

Cellulose obtained in this way from raw fibrous materials, *e.g.*, cotton, flax, hemp or ramie fibre, is a white substance distinguished by more or less lustre and translucency, retaining the structural characteristics of the raw material.

Pure cellulose is almost indestructible, and can only be brought into a state of putrefaction in the presence of nitrogenous bodies. When heated, it loses water up to a certain point, as it is very hygroscopic, but at 335° F. it commences to turn brown and then, as the heat is raised, is completely carbonised. When subjected to dry distillation it breaks up into a number of bodies such as water, carbonic acid, methane, ethane, methyl alcohol, acetic acid, and other products, depending on the temperature at which the distillation takes place, and also upon the rapidity with which the process is conducted. Cellulose is not soluble in cold or hot water up to the boiling point, even when the boiling is long continued, but if the temperature is raised under pressure as in a digester, then at over 500° F. it is completely dissolved and decomposed.

It has a specific gravity of about 1·5, and is chemically distinguished amongst the class of carbohydrates for its negative and non-reactive characteristics.

The empirical composition of pure cellulose is represented by the following formula :—

Carbon	44·2 per cent
Hydrogen	6·3 ,,
Oxygen	49·5 ,,
	100·0

This corresponds with the statistical formula, when perfectly pure and free from ash, of $C_6H_{10}O_5$, though it is probably a multiple of this, and is more generally regarded as being represented by the formula $(C_6H_{10}O_5)x$, which signifies that the cellulose molecule, in the sense of the reacting unit, is a variable quantity, and that, while under certain conditions the tendencies are towards aggregation, as in the thiocarbonate reaction, under others the tendency is towards a progressive disintegration which is notably the case in regard to the action of sulphuric acid in which there is a perfectly gradual transition from the colloid molecule to the simple dextrose unit, a crystallisable solid of low molecular weight.

There has been a considerable amount of speculation amongst chemists as to the true nature and constitution of cellulose, but there is, so far, so little experimental data on which to frame an intelligent theory, that the most of these speculations have little more than a provisional value.

In this point Messrs. Cross and Bevan[1] say as follows:—"No purely chemical synthesis of a compound similar to cellulose has been attempted; we are therefore without the essential criterion of the correctness of any general formula which might be proposed, if only as a condensed expression of the relationship and functions of its constituent groups. But although no such formula can be proposed, having any but a speculative value, it will be a useful guide to future investigation to sum up the reactions which throw a direct light upon the function of a cellulose molecule as a whole, and of its constituent groups.

1. The resolution by sulphuric acid and subsequent hydrolysis of the esters formed in the reaction into simple

[1] *Cellulose*, by Cross and Bevan. Longmans, London, 1903.

carbohydrate, viz. dextrose molecules." Cellulose is therefore, in this sense, an anhydro-aggregate of the aldose groups $C_6H_{12}O_6$.

2. Partial resolution under the action of hydrochloric acid attended by the setting free of CO groups.

In cellulose the carbonyl groups are suppressed; that is, they either exist in combination, as in the acetals, or are susceptible of an alternative form, the carbonyl becoming hydroxyl oxygen.

3. Complete proximate resolution by fusion with alkaline hydrates into hydrogen, carbonic, oxalic, and acetic acids, the yield of the latter tending to a maximum of 30 to 35 per cent, which indicates that the group $CO\text{–}CH_2$ is an important element in the constitution of the unit groups.

4. Negative characteristics. These are :—

(*a*) Those which characterise generally the "saturated" compounds, in which group cellulose must be classed.

(*b*) Resistance to alkaline reaction.

(*c*) Resistance to oxidising action up to a certain point of intensity.

(*d*) Resistance to acetylation; requiring either very high temperature or the presence of an auxiliary ($ZnCl_2$) for the determination of reactions of its OH groups with the acid oxide.

5. Synthetical reactions. Of these the most definite are those which yield esters; viz., nitrates, acetates, and benzoates. The highest nitrate attainable appears to be the trinitrate (hexanitrate in the C_{12} formula). A higher degree of acetylation has been obtained, but there is undoubted evidence that this results from molecular resolution (hydrolysis). The conclusion to be drawn from the relationship of these esters to the parent molecule is, that,

of five O atoms in the formula $C_6H_{10}O_5$, four react as OH oxygen with retention of the original configuration of the molecule.

The thiocarbonate reaction further elucidates the function of the CH groups, and the resistance of the molecule to the hydrolysis. It constitutes a further distinction of the celluloses from starch, as a type of molecular configuration; starch failing to give any definite indications of this reaction, and, in contrast to cellulose, being eminently susceptible to hydrolytic resolution.

To sum up the more prominent points in the evidence of constitution, we are entitled to regard cellulose as conforming in regard to its ultimate constituent groups to the general features of the simpler carbohydrates of well-ascertained constitution, but differentiated by a special molecular configuration, resulting in a suppression of activity of the constituent groups in certain respects, but on the other hand conferring greater reactivity in others.

While the properties and characteristics of cotton cellulose are in such-wise representative that this substance may be regarded as typical cellulose, the differentiation of this, as of every other group of tissue constituents, in conformity with functional variation, necessarily covers a wide range of divergences.

The molecular configuration involves, primarily, the question of the mode of arrangement of the carbon with the qualifying hydrogen atoms within the unit groups, which, for the reasons given, may be assumed to be of the dimensions C_6; and secondly, the grouping of these into the aggregate, which may be regarded as constituting the true molecule of cellulose.

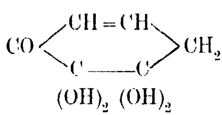
Next in importance are those modifications of configura-

tion which are bound up with the disposition of the O atoms. In regard to carbon configurations the evidences are rather indirect than determinable by the actual properties of cellulose itself. The choice obviously lies between a chain and cyclic formula for the unit groups. The balance of evidence is in favour of a cyclic formula for the following reasons.

1. The general differentiation of cellulose in regard to stability, which points to a symmetrical formula, as distinguished from the normal chain upon which the hexoses are represented.

2. The formation of a cellulose acetate of the composition $C_6H_6O(OAc)_4$, in which only $2n$ carbon valencies are taken up in "outside" combination.

3. The simple and manifold transitions of cellulose, in the plant world into keto R-hexene and benzene derivatives. The process of lignification in the plant-cell is characterised by the formation of groups of the general form :—



These groups remain intimately associated with the cellulose of the cell or fibre in combination, as a compound cellulose. These derived celluloses exhibit a close general conformity with the parent type, that is, apart from, or in addition to the special properties and reactions due to the presence of the hexene ring, in all the typical characteristics of the cellulose proper.

It appears, therefore, that cellulose may be considered as a derivative of the closed chain series of carbohydrates, that although its empirical formula, as derived from

ultimate analysis is represented as $C_6H_{10}O_6$, that this does not represent the true complexity of the molecule where it is probably always double or quadruple. This determination is based upon a study of its various synthetical derivatives, with special reference to its esters, such as the acetates, nitrates, and benzoates. In relation to the acetates, Cross and Bevan note that in cellulose regenerated from solution as a thiocarbonate, the cellulose reacts directly with acetic anhydride under what may be considered normal conditions, and the analysis of this acetate shows satisfactory coincidence of numbers for those calculated for a tetra-acetate $n(C_6H_6O.(OC_2H_3O)_4)$. The specific gravity of this acetate is 1·21. It is soluble in acetone methyl alcohol, glacial acetic acid, and nitrobenzene. It dissolves in concentrated nitric acid, and is precipitated unchanged on dilution. They consider that if this formula is confirmed by further and exhaustive investigation, that the cellulose unit must be $C_6H_6O.(OH_4)$, and this is consistent with a cyclical arrangement of the carbon nuclei, and probably a symmetrical disposition of the OH groups. There is also evidence that in pure cellulose, derived from the cotton fibre, there are no unsaturated carbon bonds, because a solution in zinc chloride exhibits no absorption of bromine, whereas in ligno-cellulose absorption occurs.

Some chemists prefer to consider cellulose as a polyose of high molecular weight, a mixture of groups of variable and undetermined dimensions, of which only the ultimate terms are known, such as CH_2OH, CHOH, and CO, but the anhydride forms of the OH groups and the position or positions of the CO groups remain undetermined and awaiting further research. More recently, however, a triacetylmonobenzoate and a tetrabenzoate have been formed,

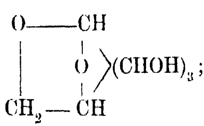
from which the presence of four hydroxyl groups may be inferred, and it is considered by some to be a triatomic alcohol, since when it is heated with acetic anhydride it furnishes a triacetyl derivative which with potash, soda, and lead oxide forms loose saline compounds which behave like alcoholates.

From the action of zinc chloride on cellulose, it has been presumed that the molecule or cellulose contains hydroxyl groups, of such a nature as to give it a salt-like property, and the solution of cellulose in zinc chloride is supposed to be due to the formation of a double salt. There also appears to be a chemical reaction of limited degree between the cellulose and dilute solutions of caustic alkalies and mineral acids.

According to Mills, the relative molecular ratio of the absorption by cellulose of alkalies and acids is represented by the formula 10NaOH : 3HCl.

From this and other considerations it appears that cellulose exhibits the properties of a feeble acid and a still more feeble base.

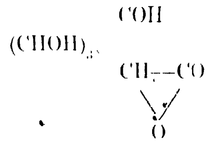
Cellulose Molecule.—Based upon a study of the highest nitrate of cellulose, and the decomposition of the nitrate by alkalies with the formation of hydroxy-pyruvic acid, Vignon has proposed to give to cellulose the following constitutional formula:—



but until further information based upon experimental data is forthcoming, it can only be received provisionally.

The same chemist from the study of the osazones of

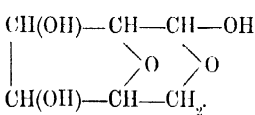
oxycellulose has ascribed to this body oxycellulose, the constitutional formula :-



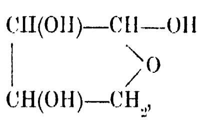
in union with varying proportions of residual cellulose.

A. G. Green (*Rev. Gen. des Mat. Col.*, 1904, p. 130) makes some interesting speculations in regard to the constitution of the cellulose molecule, and considers that the empirical formula, as usually given, $C_6H_{10}O_5$, although many reasons may be given to justify it, is not sufficiently complex, especially when viewed in the light of the formation of such compounds as the higher nitrates, which he considers could not be formed if the molecule is represented by this formula. He also is of opinion that the fact that cellulose can exist in the colloid state and is difficultly soluble must not be taken to indicate, as previously supposed, that it possesses a high molecular weight.

He proposes, from a series of investigations based on its reactions, the following formula for cellulose :—



This formula brings forward the aldehyde nature of cellulose as follows :—



which by fixation of water becomes

$$\begin{array}{l} CH(OH)—CH(OH)_2 \\ | \\ CH(OH)—CH_2—(OH); \end{array} \qquad \text{and then}$$

$$\begin{array}{l} CH(OH)—CHO \\ | \\ CH(OH)—CH_2(OH). \end{array}$$

Dreaper (*Chem. and Phys. of Dyeing*, 1906, p. 15) points out that from the ionic point of view cellulose must be regarded as an aggregate of ions which take their origin under special conditions present in the plant-cells, in which celluloses are present as mass aggregates. The cellulose aggregate is, therefore, regarded as a mixture of ions of varying dimensions. As a consequence, cellulose, as a typical colloid, has no reacting unit as a body which takes the crystalline form, nor a fixed molecular constitution such as can be represented by any constitutional formula, the cellulose molecule not being regarded as a static unit measurable in the ordinary physical units so much as a dynamic equilibrium; its reacting unit at any moment being a function of the condition under which it is placed. This view is probably generally correct, in so far as in almost every form in which cellulose may be supposed to exist in the cotton fibre there are only a few cases in which the whole of the cell-contents have attained complete conversion, at the same time, into the perfectly stable cellulose molecule, which it is only reasonable to believe, when the change in every part is complete, may be capable of expression in an empirical formula, while this may not be the case in the aggregate as usually existing, and in which it cannot react as a fixed and stable unit in the same way as would be possible if the conversion was universally complete.

Solubility of Cellulose.—Cellulose is insoluble in either water up to 400° F. or alkalies. When acted upon by concentrated sulphuric acid it is converted into dextrose. After treatment with sulphuric or phosphoric acid, iodine will colour it blue. It also gives a similar reaction when exposed to the simultaneous action of a concentrated solution of certain salts, such as zinc or aluminium chloride and of iodine. Chloroiodide of zinc, which gives a blue colour, is one of the most convenient tests for cellulose.

The cotton fibre, as it is taken from the boll when fully ripe, consists of a number of different chemical substances, and is never pure cellulose. These various bodies may be enumerated as follows.

1. Cellulose, which may be identified by the above test or by a red stain with Congo red.

2. Pectose, easily distinguished by the readiness with which it dissolved in alkalies after being previously acted upon by dilute acid or by being coloured blue when stained with methylene blue or safranin.

3. Various fats, oils, and waxes.

4. Unchanged cell-contents, such as callose, which is characterised by being soluble in soda solution, but insoluble in cuprammonium. It is coloured red-brown by chloroiodide of zinc, and a brilliant red by resolic acid or corollin.

5. Various mineral salts, such as those of potassium, sodium, lime, magnesia, iron, and sometimes aluminium.

The proportions in which these exist may be roughly estimated as follows. The composition, however, varies to a small extent with the nature of the cotton, and also the degree of ripeness, and in different seasons, of which this table is an average of three years.

ANALYSIS OF COTTON FIBRE

	Surat.	American.	Egyptian.
Cellulose	91·35	91·00	90·80
Wax, oil, and fat . .	0·40	0·35	0·42
Protoplasm and derivatives (Pectoses) .	0·53	0·53	0·68
Mineral matter (ash) .	0·22	0·12	0·25
Water	7·50	8·00	7·85
	100·00	100·00	100·00

Pure Cellulose.—To prepare pure cellulose from cotton fibre, and free it from the above impurities, it is usual to boil the fibre in a solution of from 1 to 2 per cent caustic soda, and after washing to expose it to an atmosphere of chlorine gas, and again boiling in the alkaline solution. A dilute solution of chloride of lime will remove all traces of colouring matter, and treatment with alcohol and ether removes all fat, oily, and resinous materials.

In its pure state cellulose is a very inert body, and will combine directly only with a few substances, and then only with great difficulty and under peculiar conditions. It is quite resistant to all processes of oxidation and reduction, and to hydrolysis and dehydration, this latter being indeed peculiar to the cotton cellulose, as it is not so great in the celluloses derived from other sources, which seems to indicate that in the cotton cellulose molecule there are no free carbonyl groups, which are probably the cause of greater reactivity in the other celluloses. Cotton cellulose also is specially characterised by the fact that it yields no furfurol when distilled with acid, and by being precipitated unchanged from its solution in a mixture of CS_2 and

NaOH. It will afterwards be seen that although the reactions of pure cellulose are only feeble, yet, when in the condition of cellulose as it exists in the cotton fibre, in association with a number of other bodies as enumerated above, the reactions are much more marked, and specially in regard to the mineral matter, which, although only small in extent, may and does often apparently cause reactions of a more active character.

The reactions of pure cellulose also are no guide to those which occur as soon as the cellulose molecule has been disturbed in its arrangement, as it there exhibits considerably wider affinities, and loses much of its inert character. These will be considered in their proper place, and meanwhile with pure cellulose, the reactions may be observed as follows:—

1. Action of Water upon Cellulose.—Water at the ordinary temperature and pressure has no influence upon cellulose, and even at the boiling point the cellulose remains unchanged for almost any length of time. It is true an extract of cotton may be obtained by placing cotton in water and keeping it for some length of time, and also specially when the water is heated and the cotton minced or cut into lengths. This extract, which, when the water is evaporated, yields an amorphous jelly or glue-like substance which is very hygroscopic, is not, however, obtained with pure cellulose, but seems to be derived from the soluble constituents of the fibre such as gums and unchanged cell-contents, which are more easily extracted when the fibres have been minced, because the water has more free access into the inner cavity or lumen, and so more readily comes in contact with the cell-contents. This water extract is undoubtedly of a very complex nature, and much seems to depend both in the quantity

and nature of the extract upon the precise method of extraction and the state in which the fibres are when the extract is made. Lester, in a paper published in the *Journal of the Society of Chemical Industry*, March 1902, states that a comparative test gave 1·73 per cent by weight from yarn, as against 2·11 per cent when the same yarn was cut to an average length of ¼ of an inch.

Quantities of this substance may be collected by boiling down to dryness the water in which cotton has been boiled, and Lester gives the following analysis :—

Analysis of Water Extract

Ash	39·22	per cent
Fatty Acids (thrown up by HCl)	62·30	,,
Ether Extract	17·52	,,
Cold water extract	39·50	,,
Unsaponifiable matter in ether extract of cotton	16·65	,,
Fatty acid (thrown up by HCl) in ether extract of cotton	90·98	,,
Ash of original cotton	0·82	,,
Ash of cotton after removal of water extract	0·21	,,
Ether extract of cotton after removal of water extract	0·314	,,

It is also interesting to note the difference in the results of the ultimate analysis of the ash of the water extract, as compared with the ash of the original cotton before the extract was made.

[TABLE

Chemical Constituents.	Ash of Water Extract per cent	Ash of Original Cotton per cent
Magnesium phosphate	2·65	13·10
Magnesium carbonate	6·31	5·11
Alumina	3·90	3·90
Non-oxide	trace	2·71
Silica	1·79	1·00
Calcium carbonate	3·80	13·50
Sodium carbonate	27·78	15·90
Potassium carbonate	13·82	..
Potassium sulphide	36·90	32·20
Potassium chloride	2·60	2·50
Sodium sulphate	.	4·60

While the cotton, when exposed to the air after drying, will absorb something like 8 per cent of moisture, when exposed to the air this extract will absorb something like 32 per cent, and it is therefore quite evident that it is of an entirely different nature from that of the cotton. It appears also that the cotton probably owes some of its hygroscopic property to this substance, as long as it is not boiled for any length of time or scoured or bleached. Even when pure cellulose is boiled under increased pressure it becomes acted upon in proportion to the temperature and pressure, and when the pressure is raised to 300 lbs. to the square inch the cellulose becomes completely hydrated, and is changed into hydrocellulose in which the cellulose is combined with one more equivalent of water, and changes from the double molecule $C_{12}H_{20}O_{10}$ to $C_{12}H_{22}O_{11}$.

Hydro-Cellulose.—This change is more easily accomplished when dilute acid, such as sulphuric acid, is present. Without the acid, at this pressure, however, in addition to hydrocellulose, other bodies, such as formic and acetic acid, are formed, and also dextrine-like products. The

hydrocellulose has the appearance of the cotton out of which it was formed, but it is tender and easily disintegrated. It is manufactured in large quantities for use in the process of making gun-cotton, because it is found, that if used in place of cotton and treated with the strong acid mixture necessary for forming the hexa-nitrate, it yields a more sensitive gun-cotton, that is, one which explodes more readily, and is, therefore, better adapted for use in making detonating fuses.

2. Action of Acids upon Cellulose.—Cellulose is acted upon more or less by all mineral acids, and also by many organic acids, and the extent of the action depends upon the degree of concentration of the acids and also upon the temperature. Some of these reactions are also accompanied by great physical as well as chemical changes.

Sulphuric acid, when concentrated, readily dissolves cellulose, when it forms a viscous solution, which, when water is added, causes a white, amorphous, and gelatinous precipitate which is called amyloid and has a composition represented by the formula $C_{12}H_{22}O_{11}$, a body which is allied to starch, and gives a blue reaction with iodine the same as starch, and is in fact a sugar identical with dextrose. The resolution of the cellulose molecule, by the action of sulphuric acid, appears to be a progressive phenomenon, and results in the formation of a series of sulphates. All these free acids are amorphous bodies, which are soluble in alcohol and water, and when boiled are completely hydrolised to glucose and sulphuric acid. They also form a complete series of salts with such bases as potash, soda, lime, baryta, and metallic oxides such as lead.

If the cellulose is treated with weak acid it is, after a time, completely disintegrated, as the result of hydrolysis

whereby a molecular change occurs in the fibre substance, reducing it into a fine powder, which is a hydrate of cellulose, and which has the composition indicated as above, $C_{12}H_{22}O_{11}$. The action of heat greatly increases the rapidity of the decomposition.

Carbonising.—Upon this reaction the carbonising process for the extraction of vegetable fibres from wool or woollen rags of mixed goods is founded. When raw wool is received from the farmer it always contains burrs, straw, and other vegetable matter entangled along with it, and which, in many cases, consist of fragments too small to be picked out, and unless these are removed injury is caused in the cloth by the fact that the vegetable and animal fibres will not dye equally well; and so wherever these small fragments of cellulose are present they leave defects in the cloth, in the form of light-coloured spots. These defects are specially liable when certain colonial wools are used which have large quantities of vegetable seed entangled in the fleece. The process is also equally useful where rags are employed to make shoddy or mungo, in which it is often necessary to remove the cotton warp, which, if mixed with the wool, would cause defects in the goods as above. It is usual now only to apply this process to the raw wool and rags, and not to piece goods, because it is absolutely necessary that the wool should be clean, and free especially from any fatty matter, as if any is present it is fixed by the carbonising agent upon the fibre in such a manner that it can scarcely be removed by washing, and unless removed causes trouble and defects in dyeing, exactly the same as the vegetable matter. Also in goods, cotton or silk is frequently used along with the wool in the body of the piece or in the selvage, and these would be destroyed in the process. It is found also

that the carbonising agent need not be sulphuric acid as above, as this, unless very dilute, is apt to attack certain parts of the wool, and injure its lustre, or form coloured compounds with it, which cannot afterwards be removed, and which are a great disadvantage where light colours are afterwards to be dyed. In some cases, therefore, it is advantageous to substitute for the sulphuric acid certain other acid salts such as the chloride of magnesium or aluminium, although a higher temperature is necessary to effect the reaction than when sulphuric acid is used. With the chlorides the ultimate chemical effect is the same in producing the hydrocellulose, and the earthy bases also are removed like the cellulose in a fine powder which can be shaken out. When the solution of acid or acid salt is strong a lower temperature is required, but this not unfrequently causes defects, and it is therefore usual to use low strengths and higher temperature.

When sulphuric acid is employed the strength is about 2° B., and the temperature about that of boiling water, 212° F. Where magnesium chloride is used the strength which is found best is about 9° B., and specially if the wool is of a fine quality, and the temperature required is a little over 300° F. As soon as the reaction is complete, the removal of the residual salt must be undertaken at once, as an oxychloride with a strong alkaline reaction is left behind, and this will rapidly attack the wool fibre and injure the lustre, even if it does not tender the wool. Where aluminium chloride is used the strength required is 7° B., and care must be taken to have the salt as neutral as possible. The temperature required is about 300° F., and as in the case of magnesium chloride an oxychloride is left behind, but in this case the reaction is acid and not alkaline. In both cases the greatest care must be exercised that the

wool is free from grease, or metallic soaps are formed, which cannot be removed by washing afterwards. The time required to carbonise depends on the reagent used. With sulphuric acid of the strength named above about twenty to twenty-five minutes' exposure to the temperature is sufficient. With magnesium chloride forty-five minutes and with aluminium chloride about an hour.

In the choice of the reagent to be used it is important to consider the nature of the dye to be employed on the wool afterwards, as if acid, the sulphuric acid process is best, because it will not require to be neutralised, whereas this is necessary where alkaline dyes are to be employed. This neutralisation is usually conducted by means of soap and soda, the former restoring in some degree the softness which has been rendered dry and harsh by the action of the carboniser. For neutral dyes when aluminium chloride has been used, no after treatment is required, as in the case of magnesium chloride, which for alkaline dyes requires to be neutralised with dilute acid. Sulphuric acid and magnesium chloride are the two agents most frequently used. Care must be taken that the wool is thoroughly and uniformly impregnated with the dilute salt or acid solution before passing into the stove; and when it is taken from the stove, the wool must be willowed at once, while the carbonised material is dry and brittle, and then the washing must be complete, either with water in the case of the salts, or the soap and soda with the acid, so as to remove all traces of the reagent. Special care must be taken in the case of the neutralisation of the acid to remove all traces of the soda, or this will cause stains in the goods when certain dyes are employed.

Vegetable Parchment.—When unsized paper is treated with strong concentrated sulphuric acid (sp. gr.

1·66 to 1·75) there is formed on the surface a gelatinous layer of hydrate of cellulose, which fuses the fibres together, and forms, when the paper is washed, pressed, and dried, a compact surface of amyloid, which gives the paper the same appearance as parchment, and is now used in place of it. The paper used for this process must be unsized and porous, the same as blotting paper, because it is essential that it should only be exposed to the action of the acid for as short a time as possible, so as to prevent an undue rise in temperature, and also to change as quickly as possible the solution of cellulose in the sulphuric acid to the condition of amyloid, by passing it immediately into a large quantity of water, contact with which immediately throws down the amyloid and sets free the sulphuric acid, which can then be concentrated again for further use. A few seconds only are required to effect the change, and as there is a limit to the thickness of paper which can be used, on account of the time taken by the acid to penetrate the paper; if greater thickness is required than can be conveniently treated, two or more sheets are rolled together while the amyloid is in a viscous condition, and thus any required thickness can be built up. The paper shrinks in both thickness and width under the process, and after neutralising the acid in an alkaline bath the paper is stretched by suitable means during the process of drying, both lengthways and laterally, or it would, when passed between the drying rollers, shrink unequally. The change effected by the action of the acid, after washing with water, is strictly mechanical, as the parchment has the same composition as the cellulose. When dry the parchment has a hard horn-like consistency, and when flexibility is required it is treated by immersion in strongly hygroscopic bodies, such as magnesium or calcium chloride or glycerine, which

makes it pliable and more elastic. This treatment renders the paper grease-proof, so that it is now largely used as a packing material for goods which are greasy or require protection from grease, and also at the same time the tensile strength of the paper is greatly increased. This increased strength and resistance to moisture, which it possesses in a high degree, as it can be boiled without disintegration, render it suitable for many purposes in the arts and manufactures; for example, luggage labels, which cannot be easily torn or destroyed by rain, as a covering for preserve jars so as to prevent the entrance of moisture or germs which cause mouldiness, for making dialysers, for backing books, etc.

Artificial horsehair, which can hardly be distinguished from the real hair, and possessing even as great an elasticity, is now prepared in a similar manner from the fibre derived from some species of grasses.

Hydrochloric acid, whether in the liquid or gaseous form, acts energetically upon the cellulose molecule, and indeed the action of the hydrolysing agents employed in the carbonising process in the form of chloride salts depends on the liberation of chlorine by the heat in presence of the moist cellulose. The compounds formed with hydrochloric acid and cellulose are similar to those formed with sulphuric acid, though the products are chlorides and not sulphates; the changes through which they pass are not therefore the same, although the ultimate products are so much alike, the hydrochloric acid taking the place of the sulphuric acid in the combinations.

As both these acids are used in the treatment of the yarn and cloth in dyeing and bleaching, the above reactions show the absolute necessity of careful washing so as to remove the last traces of acid, otherwise a tendering and

ultimate destruction of the fibre is sure to result, and specially when either has to be exposed to the action of heat, as is frequently the case in finishing. Even without heat weak mineral acids readily form feeble compounds with cellulose which are spontaneously decomposed in the presence of moisture and air, and the acid is immediately liberated and can thus act upon a fresh portion of the undecomposed cellulose, and thus the mischief is continued so long as the acid is brought into contact with fresh portions of the material.

Electric Lamp Filaments.—A concentrated solution of zinc chloride acts upon cellulose, and especially when the solution is heated and the cellulose digested in it for some time, and forms a viscid syrup. This solution is now employed extensively in the preparation of cellulose filaments, which, after carbonising, are used in the manufacture of the incandescent electric light in place of those which were formerly obtained from cotton or ramie threads or fibres of cane or other materials. These are found to be much more homogeneous in character, have a greater elasticity, and more uniform electrical resistance than those obtained from any other source. To prepare this solution it is found in practice that it is best to take one part of bleached cotton fibre and dissolve it in a mixture of six parts of anhydrous zinc chloride with ten parts of water. When the mixture has been raised to a temperature of about 160° F., with constant stirring, the whole of the cotton becomes dissolved, and the heating is then continued for some time on a water bath, so that the temperature is kept uniform, and water added from time to time to replace that lost by evaporation, until a perfectly homogeneous gelatinous syrup is obtained. This syrup is then forced through glass nozzles into alcohol, which precipitates the

syrup in a continuous thread, which is hardened by the alcohol. These threads are then washed with hydrochloric acid to remove the zinc, and after washing are carbonised by an electric current in an atmosphere of coal gas.

A solution of zinc chloride in hydrochloric acid, one part of zinc to two of the acid, dissolves cellulose readily in the cold, and the cellulose can be precipitated from this solution, when fresh, by the addition of water in an unchanged but colloid condition, but if the solution is allowed to stand, a change in the composition occurs, and the cellulose is converted into dextrine and other bodies which are entirely soluble in water.

Incandescent Gas Mantles.—Filaments are also now prepared in a similar way for use in the manufacture of incandescent mantles. In the early days when mantles were first used a cotton fabric was employed as the base of the mantle. This was soaked in the solution of salts of the rare earths, and when the mantle was burnt in order to change the nitrates into oxides, the incinerated mantle was then soaked in collodion, and when this was dried so as to evaporate the solvent, the mantle could be transported, without fracture, and handled until it was placed on the burner and the collodion film burnt off so as to render it fit for use.

The mantle made from cotton had a good, smooth appearance, and a fairly uniform texture. Some years ago the cotton base was replaced by one made from ramie fibre, which, although not so smooth and uniform as the cotton, had the great advantage that it was more stable, and the illuminating power, when the mantle was in use, did not fall off, in the same time, to the same extent as the cotton mantle, and it also gave a more uniform and constant light. After being used one hundred hours, the falling off in

photometric intensity was not more than 10 per cent, which was much less than the cotton mantle under the same conditions. The preparation was the same in both cases.

Recently a new material has been introduced in Germany called "Ceroférm," which is a reticulated cellulose film, apparently prepared in the same way as the filaments for the electric glow lamps.

Mantles made from these materials seem to be as advantageous for incandescent gas-burners as the celluloid film for the electric light. The appearance of the mantle is much better and smoother, and more regular in texture than either cotton or ramie, and it also yields a firmer ash when incinerated to form the oxide of the salts with which it requires to be impregnated; and it appears after the final burning off of the collodion on the burner to conserve the luminous qualities for a longer period than even the mantle made from ramie fibre does. The use of the cellulose compounds, both in the texture of the mantle and its preservation, opens up a wide field for further industrial applications. Even after the final incineration, the mantle which, when made either from cotton or ramie, is exceedingly brittle and easily broken, in the case of the cellulose fibre can be handled and even squeezed and bent double without any deterioration, which is a great advantage, and specially in the case where the burner is subject to any vibration.

CHAPTER VII

CHEMISTRY OF THE COTTON FIBRE—*continued*

Action of Nitric Acid on Cellulose.—Nitric acid, as an acid hydrate, enters into reaction of double decomposition, with bases, basic hydrates (alkalies), and with salts.

It also enters into double decomposition with a number of hydrocarbons not in any way possessing alkaline characteristics, and not reacting with other acids. Under these circumstances the nitric acid gives water and a new substance, which is called a nitro compound. The chemical character of the nitro-compound is the same as that of the original substance. For example, if an indifferent substance be taken, then the nitro-compound obtained from it will be indifferent also. Benzene, for instance C_6H_6, acts according to the equation $C_6H_6 + HNO_3 = C_6H_5NO_2 + H_2O$, which is nitro-benzene, and is employed in large quantities for the preparation of aniline and aniline dyes.

The action of nitric acid upon carbohydrates is very similar, and forms along with them a series of nitrates of various degrees of nitration, depending on the temperature and strength of the acid, and upon the length of time that the action is continued, and many of these bodies are of the greatest importance in a technological sense.

Strong nitric acid, when permitted to act on cellulose, completely decomposes it and oxidises it to oxalic acid.

When boiled with moderately concentrated nitric acid cellulose is converted into a structureless friable substance, which possesses great affinity for basic dyestuffs, and which is called oxycellulose, which has a composition corresponding to the formula $C_{18}H_{26}O_{16}$.

It dissolves in a mixture of nitric and sulphuric acids, and on pouring into water a nitrate of cellulose, having the formula $C_{18}H_{23}O_{13}(NO_3)_3$, is formed. The by-products of this oxidation are carbonic and oxalic acids, together with lower nitrogen oxides, and the reaction seems to be first the formation of hydrocellulose, and then as a second process the oxidation of the hydrocellulose into oxycellulose. In general it exhibits a close resemblance to the pectic groups of colloid carbohydrates, and from the low number of hydroxyl groups reacting with the nitric acid it seems conclusive that it is a condensed, as well as an oxidised derivative of cellulose.

The variation in the strength of the acid makes considerable differences in the product obtained, and Vielle (*Compt. Rend.* vol. xcv. p. 132) gives the following products as obtained with acid of various strengths:—

[TABLE

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TABLE OF NITRO-CELLULOSES

Density of Nitric Acid.	Products Obtained
1·502 1·497	Structural features of cotton preserved, soluble in acetic ether, not in ether-alcohol. $C_{24}H_{20}(NO_3)_{10}O_{10}$.
1·496 1·492 1·490	Appearance unchanged, soluble in ether-alcohol, collodion cotton $C_{24}H_{22}(NO_3H)_9O_{11}$. $C_{24}H_{24}(NO_3H)_8O_{12}$.
1·488 1·483	Fibre still undissolved, soluble as above, but solution more gelatinous and thready. $C_{24}H_{26}(NO_3H)_7O_{13}$.
1·476 1·472 1·469	Dissolve cotton to viscous solution; products precipitated by water, gelatinised by acetic-ether and not by ether-alcohol. $C_{24}H_{28}(NO_3H)_6O_{11}$.
1·463 1·460 1·455 1·460	Friable pulp, blued strongly by iodine in KI solution, and insoluble in alcohol. $C_{24}H_{30}(NO_3H)_5O_{15}$ $C_{24}H_{32}(NO_3H)_4O_{16}$.

The highest nitrate obtained as above, with nitric acid only, is somewhat lower than when sulphuric acid is present. Under these latter conditions the highest nitrate attainable is represented by the formula $C_{24}H_{18}(NO_3H)_{11}O_9$.

These views are now, however, considerably modified by the fact that since these investigations were made, a series of researches on the composition and properties of the various nitro-celluloses have been undertaken by Messrs. Bebie and Lunge, which were published in 1901 in the *Zeitschrift fur angewandt Chemie*, and which show a series of much higher nitration; and the results of the action of nitric acid upon cellulose may be considered as producing the following series of nitro-celluloses, in which

the simple formula $C_6H_{10}O_5$ is quadrupled in order to avoid fractions:—

TABLE OF NITRO-CELLULOSES

Name	Formula
Dodeca-nitro-cellulose . .	$C_{24}H_{28}O_8(NO_3)_{12}$
Endeca- ,, . .	$C_{24}H_{29}O_9(NO_3)_{11}$
Deca- ,, . .	$C_{24}H_{30}O_{10}(NO_3)_{10}$
Nono- ,, . .	$C_{24}H_{31}O_{11}(NO_3)_9$
Octo- ,, . .	$C_{24}H_{32}O_{12}(NO_3)_8$
Hepta- ,, . .	$C_{24}H_{33}O_{13}(NO_3)_7$
Hexa- ,, . .	$C_{24}H_{34}O_{14}(NO_3)_6$
Penta- ,, . .	$C_{24}H_{35}O_{15}(NO_3)_5$
Tetra- ,, . .	$C_{24}H_{36}O_{16}(NO_3)_4$
Tri- ,, . .	$C_{24}H_{37}O_{17}(NO_3)_3$
Di- ,, . .	$C_{24}H_{38}O_{18}(NO_3)_2$
Mono- ,, . .	$C_{24}H_{39}O_{19}(NO_3)$
Cellulose (pure) . .	$C_{24}H_{40}O_{20}$

According to the above authorities the degree of nitration from the tetra-nitro-cellulose to the deca-nitro-cellulose can only be obtained by treating cotton with nitric acid, while for still higher degrees mixtures of nitric and sulphuric acids must always be employed. Since, however, in the preparation of nitro-cellulose on the large scale the mixture of acids is always employed, they were always used in these researches. It is important to note that the nitro-celluloses exhibit considerable variation in regard to their solubility in various reagents, and it was formerly regarded that this solubility was least in the higher nitrates. It is now found, however, that this division does not hold strictly correct, as nitro-celluloses can be obtained

with nearly the same content of nitrogen, the one of which is soluble and the other insoluble. It is, also found that the utmost importance attaches to the proportions in which the two acids are used, because if the sulphuric acid is in excess it seems to exercise a retarding action on the progress of the nitration and also upon its uniformity. Excess of the sulphuric acid probably changes the molecular character of the fibres, in the same way as it acts upon them in the formation of vegetable parchment, and renders them less susceptible to the action of the nitric acid. This is of considerable importance in the technical application of these nitrating processes, because in the case of the nitrates which are to be used in explosives, no soluble constituents in the product are required, while in those which are to be employed in the manufacture of colloid products great solubility is of advantage.

There is a general correspondence, however, between the degree of nitration and its solubility in nitro-cellulose compounds, and it is found also that the degree of nitration affects the optical qualities of the compounds, when examined by polarised light, just in the same way as Hartley found that in some aromatic compounds definite absorption bands, in the more refrangible regions of the spectrum, are only obtained in substances in which the three pairs of carbon atoms are doubly linked, as in the benzene group, while Abney and Festing found that the radical of an organic body is always represented by certain well-marked absorption bands differing, however, in position according as it is linked with hydrogen, a halogen, or with carbon oxygen or nitrogen. Indeed, it is not improbable that by this method of examination, where the bodies are soluble, the hypothetical position of any hydrogen, which is replaced, may be identified, and this result has

been rendered all the more probable by the researches of Perkin on the close connection which always exists between chemical compounds and their optical properties.

Use of Polarised Light.—In the *Journal of the Society of Chemical Industry* for May 1907 an interesting paper appears on this subject by H. D. Mosenthal, F.I.C., and from this it appears that the degree of nitration does exercise an influence on the appearance of the fibre, when examined by polarised light, and also on the rotary power and refractive index; and it appears also from a statement made by Bersch in his work on cellulose[1] that M. Chardonnet uses polarised light to examine the quality of the nitro-cellulose for use in the manufacture of artificial silk. When the field of view shows exclusively blue-appearing fibres, and no yellow ones can be seen, it is, at all events, a proof that the total quantity of cellulose which has been used has been nitrated, and that the product will probably be completely soluble.

The degree of nitration and solubility, along with the appearance under polarised light, are given by Mosenthal as follows: "The observations were all made with a magnification of thirty diameters, and were observed in daylight, after the fibres to be examined were all moistened, so as to render them more transparent, with 50 per cent ethyl-alcohol." He also remarks for determination of detail in structure he never uses polarised light, but only to distinguish between nitrated and non-nitrated cotton fibres *inter se*.

In the same journal also, but at an earlier date, papers are found by Knecht and also by Hübner on these phenomena.

[1] *Cellulose*, by Dr. Joseph Bersch. Kegan Paul, London, 1904.

TABLE OF NITRATION EFFECTS AS EXAMINED BY POLARISED LIGHT

No.	Material Nitrated.	Nitrogen per cent	Appearance in Polarised Light	Soluble per cent
1	Cotton	13·50	Light-blue	0
2	,,	13·20	Light blue 15 per cent .	10
3	,,	12·95	Blue grey- slate grey .	80
4	,,	12·41	Bright blue . . .	100
5	,,	12·37	Dark blue . .	100
6	,,	12·33	Bluish grey . . .	98
7	,,	12·30	Dark blue, some fibres orange or yellow	99
8	,,	12·29	Dark blue, some fibres orange or yellow	100
9	,,	12·27	Faint blue, some fibres dull pink	98
10	,,	11·96	Red or orange, 25 per cent dark blue	100
11	,,	11·36	Does not polarise, only an occasional colourless fibre visible	100
12	,,	11·19	50 per cent orange, 50 per cent dark blue	98
13	,,	11·10	Straw colour, occasional fibre dark blue	100
14	,,	10·86	Dull orange . . .	98

He does not, however, regard the method as reliable, because he further remarks, "Nitro-celluloses of the same degree of nitration, prepared by different methods as to temperature, acid mixture, and time of immersion, show different colours in polarised light, and the appearance differs with the raw material used, such as cotton, wood-cellulose, ramie, or flax. Dry fibres do not present the same appearance as when moistened, and the colours not only vary with different liquids, but with the same liquid in different degrees of dilution. The colours, moreover, are also affected by the different degrees of magnification, and also whether seen with artificial or natural light."

The author made a series of experiments on this subject some years ago, and found that if the cotton was always prepared in the same way, the fibre being the same as regards thorough washing and uniformity in proportion of mixture of acids and also density, temperature, and time of treatment, the fibres appeared almost uniformly blue and completely soluble. Care was also required to see that the same degree of moistening with alcohol was used, and it was concluded that the use of the polariscope was a fairly reliable though rough method of detecting the uniformity of the nitration, and therefore of the solubility.

Many of the nitrates of cotton are of comparatively little use, and for industrial purposes they may be considered as of two kinds. The insoluble is represented by the hexa-nitrate and has the composition given in the table of nitro-celluloses, having the formula $C_{24}H_{34}(NO_3)_6$, and is insoluble in alcohol, ether, or in mixtures of both, in glacial acetic acid or methyl-alcohol, but is slowly soluble in acetone.

Effect of Water on Nitrations and Solubility.—All the lower nitrates are more or less soluble, and it is extremely difficult to prepare any of the nitrates in a state of purity, as they are so easily produced side by side in consequence of the action of the acid upon the individual fibres which are not all in exactly the same receptive condition, and however carefully prepared there is always more or less variation in the acid mixture present. In gun-cotton, which should be all the hexa-nitrate as above, it is not unusual in commercial samples to find as much as 10 to 12 per cent of soluble nitrates present in it. This largely depends upon the content of water in the acid mixture, as will be seen by the following table given by

Bersch,[1] which gives the varying degrees of solubility in the product derived by treating the cellulose with varying mixtures of the acids and water, and which is of great scientific as well as industrial interest :—

TABLE OF VARYING SOLUBILITIES DEPENDING ON STRENGTH OF ACIDS

Nitrating Mixture			Solubility in Ether-Alcohol 3 to 1.	Yield
Sulphuric Acid, H_2SO_4.	Nitric Acid, HNO_3.	Water, H_2O.		
45·31	49·07	5·62	1·50	177·5
42·61	16·01	11·38	5·40	176·2
41·03	44·45	14·52	22·00	170·3
40·68	43·85	15·49	60·00	167·0
40·14	13·25	16·61	99·14	159·0
39·45	42·73	17·82	99·84	153·0
38·95	42·15	18·90	100·02	156·5
38·43	41·31	20·26	99·82	144·2
37·20	40·30	22·50	74·22	146·0
36·72	39·78	23·50	1·15	138·9
35·87	38·83	25·30	0·61	131·2
34·41	31·17	28·42	1·73	129·3

He explains the great difference between the soluble and insoluble parts as arising from the dilution of the nitrating mixture by the water generated in the course of the reaction and the nitric acid withdrawn by the nitration of the fibres; and recommends that, in order to secure the most uniform results, the operation should always be conducted with as large a proportion of the nitrating acids in regard to the quantity of cotton as possible, so as to make the effect of the dilution arising from this cause as small as possible.

[1] *Cellulose*, by Dr. Joseph Bersch. London, 1904.

In looking at the table it will be seen that as the proportion of water is increased there is a gradual rise in the solubility of the products, until a maximum of perfect solubility with 38·95 SO_4H_2, 42·15 HNO_3 and 18·90 H_2O, and it appears, therefore, that when the percentage of water remains constant in the nitrating mixture at from 17 to 20 per cent, the perfectly soluble collodion nitrates are obtained.

The degree of dilution of the acid also greatly affects the mechanical structure of the cotton undergoing nitration. Up to about 15 per cent of water, which is the maximum which can be used in preparing the higher nitrates, very little alteration in the physical structure of the cotton is observed, and the only change appears to be in a harsher feeling and a greater tendency to electrical excitation under friction; but when the water content rises beyond this figure, the structural features of the fibre commence to be destroyed, the individual fibres rupture and crumble into a friable mass when dried, and felt together in knotty masses.

For the preparation of the higher nitrates to form the insoluble and highly explosive compounds, strong acid is required, and the mixture is usually one part nitric acid (sp. gr. 1·52), with three parts sulphuric acid (sp. gr. 1·84) by weight, when the hexa-nitrate is produced, and this substance is the gun-cotton used as an explosive, either separately or in mixture with other bodies to increase or restrain its action.

Gun-cotton (pyroxylin) is usually made from cotton waste, unless required, as it is sometimes for certain purposes, in the skein, in which case coarse counts of cotton yarn are used. The cotton waste or yarn is first thoroughly cleansed, so as to remove all greasy or other

adherent matter by treating with alkali, washing, and drying. The acids to be used are then prepared of the requisite strength, and are stored in separate stone-ware jars or cisterns, with taps, so that they can be run out in the requisite proportions into the mixing vat, which is also of stone-ware. This vat is furnished with a cast-iron lid and a tap for drawing off the contents. There is an opening in the lid through which a glass stirrer can be introduced, so as to stir the acids together as they are run in the requisite proportions simultaneously from the store cisterns into the vat. When the mixing is complete, the contents are allowed to stand for several hours until the acid solution is perfectly cold. A portion of this cold acid is then drawn from the mixing vat and run into an earthenware vessel or jar, standing in water and provided at the side with a perforated iron or stone-ware shelf, upon which the cotton, after immersion, can be placed to drain off the excess of acid. The dry cotton which has been thoroughly cleansed is then immersed in the acid, a small quantity at a time, and stirred round in the jar with a stirrer which brings all parts of the cotton into contact with the acid. A considerable rise in the temperature of the acid takes place in consequence of the chemical reaction, and the water surrounding the mixing vessel is intended to keep this temperature down, and care must be exercised to regulate the feeding of the cotton so as not to permit an undue rise. As each batch of treated cotton is placed upon the strainer, a fresh quantity of cold acid is let in to the jar to supply the loss taken up by the cotton. A large part of the cotton is changed into the hexa-nitrate by this preliminary treatment; but so as to secure the conversion of the whole the cotton is then removed from this jar and placed in another, in which it is pressed down and covered

with acid, and allowed to remain in contact with the acid for twelve hours. This jar is also standing in water and covered by a lid usually of stone-ware.

At the end of this time the cotton is removed from this vat, and transferred to a centrifugal hydro-extractor, by means of which all superfluous acid is removed and returned to the store cistern. The cotton is then plunged suddenly into a cascade of cold water to prevent any rise in temperature, which would occur if a small quantity was used, and then, when thoroughly washed, again treated in a centrifugal extractor so as to remove the water. This washing is continued until all trace of acid is completely removed. The cotton is then reduced to a pulp in a rag engine, the same as that used by paper-makers, and then the pulp is thoroughly washed again for about forty-eight hours in a poaching machine, with warm alkaline water, so as to remove the last traces of acid, if any has remained, and then washed again in pure water. The pulp is then drained and moulded into discs, or any other required form, by hydraulic pressure, until it has the required density, and then slowly dried upon heated plates. When the discs leave the press, they usually contain about 20 per cent of moisture, and in this state can be cut up or bored with perfect safety.

When gun-cotton is dissolved in ethyl acetate or acetone a gelatinous solution is obtained. After the removal of the solvent an amorphous transparent substance is left, having the same formula as the gun-cotton, but having an entirely different molecular structure, which causes it to explode much more slowly and with less violence than gun-cotton, which, on account of this, and the fact that corrosive products are formed when the gases are liberated under pressure, is rendered unfit for use in artillery.

This new substance can be graduated to give any required pressure on explosion, and forms the base of the manufacture of smokeless powder, which has not the same corrosive effect on the guns.

Although gun-cotton is not soluble in ether-alcohol it can be dissolved in acetic-ether, acetone, benzole, and nitro-benzole, but not in nitro-glycerine itself.

Blasting-gelatine, one of the most powerful and effective blasting agents, is, however, prepared by dissolving gun-cotton in a mixture of nitro-glycerine and acetone.

Gun-cotton is not only used by itself as an explosive for military and engineering purposes, but it is also associated, so as to increase the rapidity and force of the explosion, with a mixture of inorganic salts or aromatic nitro-derivatives which contain large quantities of oxygen such as chlorate of potash, so that the oxygen may be available within the substance so as to aid the process of combustion. It is also used in admixture with, or solution in, various other nitro-compounds, such as nitro-glycerine, to form ballistite, melanite, cordite, and a numerous family of similar products.

The lower nitrates can either be obtained from the higher, or produced independently by graduating the strength and temperature of the nitrating acids.

Cellulose Penta-Nitrate, $C_{24}H_{35}O_{15}(NO_3)_5$, may be obtained by dissolving the hexa-nitrate in nitric acid, at a temperature of about 180° to 190° F., and then precipitating by the action of sulphuric acid, after washing with water to remove the acid and then with alcohol; the substance is then dissolved in ether-alcohol, and reprecipitated by the addition of water. The action of strong caustic potash on the penta-nitrate converts it into the di-nitrate of cellulose, $C_{24}H_{38}O_{18}(NO_3)_2$.

Cellulose Tetra-Nitrate, $C_{24}H_{36}O_{16}(NO_3)_4$, and **Cellulose Tri-Nitrate,** $C_{24}H_{37}O_{17}(NO_3)_3$, are formed simultaneously when cellulose is treated at a higher temperature, and for a shorter time with more dilute acid than is necessary to produce the higher nitrates; and as they are both equally soluble in the three solvents, ether-alcohol, acetic-ether, and methyl-alcohol, they cannot be separated from each other. Their production seems to be a part of the continuous process for the production of the higher nitrates, because, if treated with more concentrated acid, they are further converted into the hexa-nitrate and penta-nitrate, which are separable. The action of strong alkalies, such as caustic potash and ammonia, converts them into the di-nitrate.

When these nitrates, and indeed any of the lower nitrates, are dissolved in ether-alcohol or other solvents, such as amyl-acetate or benzene, they form transparent viscous solutions, which leave, when the solvent is removed, a continuous clear film, which is of considerable elasticity and tenacity. This substance is called *Collodion*, and is of the greatest use in the industrial arts in the production of a series of products, such as artificial silk or lustre-cellulose, and also in surgery and photography.

Collodion.—The great importance of the soluble products of nitro-cellulose took its rise when, in the early days of photography, a collodion film was required on the surface of the glass plates used in the wet process, although now they have been replaced generally by a gelatine surface on the dry plates.

Collodion is usually and best prepared by dissolving the tetra- and tri-nitrate of cellulose in the mixture of ether and alcohol, in which, unlike the hexa- and higher nitrates, they are completely soluble, and yield, on the solution

being permitted to evaporate, when poured out on to a clean smooth surface, a clear transparent colourless film of great uniformity and considerable tenacity. These nitrates are also soluble in amyl-acetate and benzene, when on evaporation they yield a similar film, but with rather different physical properties. Care must be taken in the preparation of the tetra- and tri nitrates to obtain these products in a pure state and free from admixture with either the higher or lower nitrates, as in the former case the nitrated cotton will not be completely dissolved, and in the latter there will be a want of perfect transparency in the film, which will only be translucent and not perfectly transparent. The table on page 168 shows that, to obtain the best results, the proportions of the acids to be used in nitrating the cellulose must be in the proportions as follows:—

Nitric	Acid (HNO_3) . . .	42·15	per cent
Sulphuric	,, (SO_4H_2) . . .	38·95	,,
Water	(H_2O) . . .	18·90	,,
		100·00	

To make the best collodion suitable for photographic, medical, and other purposes, it is essential that the nitrated cotton is perfectly neutral before being dissolved in the ether-alcohol. To secure this it is best to soak the cotton for at least half an hour in a mixture of strong ammonia diluted with four times its volume of water; and, after thorough washing in a large volume of running water, it must be completely dried at the temperature of boiling water, 212° F.

The ether-alcohol solvent is made with 50 parts of ether to 50 parts of 95 per cent alcohol, and in this mixture

2 parts by weight of cotton is dissolved. The clear solution is then placed in tall glass-stoppered bottles of small diameter, and any insoluble material slowly settles to the bottom, and the clear solution can be decanted off and is ready for use.

The principal use for collodion in medical practice is for the purpose of forming an artificial skin which prevents the entrance of organisms or dirt which are detrimental to the process of healing, and beneath the surface of which new growth of skin can take place.

In addition to the use of collodion for photographic and medical purposes it is now employed largely in the manufacture of toy balloons, which are made in the following manner. They are now frequently employed for advertising purposes.

The collodion is poured into a dry Florence flask, which is turned round quickly until the whole inside surface is covered with a thin layer of the emulsion. The neck of the flask is also covered, so that when the solution has evaporated a thin layer of cellulose is deposited in the form of the flask. When all the ether has been driven off, the film is easily detached from the surface and drawn up through the neck of the flask, distended with air and permitted to dry. A balloon only weighs about two grains, and floats easily when filled with coal gas or hydrogen.

Artificial india-rubber is now being manufactured on a considerable scale from the soluble nitro-celluloses. These are prepared in the same way as for collodion, but the same extreme care is not quite so necessary. The solvent usually employed is a mixture of equal parts of ether and alcohol, although sometimes acetone and methyl alcohol are used. The quantity of solvent used is only

enough to permit the cotton to be formed into a thick gelatinous mass, which is then placed in a mechanical kneader, the same as is used for mixing dough, putty, and other viscid masses. While in this condition, castor oil, boiled oil, or other similar oils are introduced in suitable quantities to be determined by the use to which the substance is to be afterwards applied. The kneader is connected with suitable condensing apparatus, by means of which a large portion of the solvent is recovered for use over again. The castor oil, intimately mixed with the cellulose mass, after the solvent has been almost removed, confers upon the magma a certain degree of flexibility and elasticity, which prevents the mass, when removed from the kneader and rolled into sheets, from becoming brittle: sometimes flax waste digested in boiled linseed oil is incorporated in the mass to give it tenacity when it is to be used for mats and similar articles.

During the kneading a current of warm air is aspirated through the machine, which greatly assists the evaporation and carries the vapour of the solvent to the condensers. The degree of elasticity in the resulting product depends on the proportions of the solvent, oil, and nitro-cellulose, and the mass when being mixed and rolled can be associated with any material, such as chalk, asbestos, flax or hemp waste, and other materials to bring it to any required consistency, and the resulting material can, when heated, be moulded into any desired shape and coloured during the mixing process to any tint by the use of suitable pigments. Although this artificial rubber is inflammable it is not explosive, and is rendered less so when mixed with non-inflammable materials as above. If perfect non-inflammability is required a surface treatment with a hot alkaline solution such as soda, denitrates the outer

layer, and renders it safe even when in contact with flame.

These compounds have probably a great industrial future before them, as for very many purposes they can be employed as a perfect substitute for rubber. They possess also high electrical resistance properties, and the subject is deserving of careful consideration by electrical engineers and cable manufacturers.

Celluloid.—Soluble nitro-cellulose, the same as prepared for the production of collodion, has the peculiar property of entering into combination with camphor ($C_{10}H_{14}O$) and other similar bodies when the two are intimately mixed together.

Whether the mixture, when completed, has undergone a chemical change and forms a new compound, or whether the product is only a mechanical mixture, is uncertain, and the question up to the present time has not been completely investigated. The fact that the nitro-cellulose, which before mixing with the camphor is very explosive, and after the mixture loses this property and becomes simply highly inflammable, when it burns brightly with a yellow smoky flame, seems to point to some kind of chemical change, but on the other hand it is known that a sufficient admixture of non-explosive material will prevent detonation, even in highly explosive bodies.

Properties of Celluloid.—Celluloid is a hard elastic transparent body, closely resembling horn or tortoiseshell in appearance, and can be made, when mixed with other materials, to imitate coral, ivory, and other similar bodies. It can also easily be stained to any required colour, when suitable pigments are used, or it is mixed with other different coloured substances. It can be made to vary in its mechanical properties also by varying the method of

its manufacture, so that it can possess any degree of hardness and elasticity, when it can be sawed or turned in a lathe. It does not possess any structure, being amorphous, and therefore has no molecular difference in any direction, which gives it an advantage over most other bodies, since it can be worked equally well one way or the other. When subjected to heat it can be made soft and pliable, so that it can be bent into any form, and if the heat is increased it may be rendered sufficiently soft to be pressed or moulded into any shape. The temperature of boiling water, 212° F., is sufficient to render it soft and pliable, and when raised to 250° F. it becomes as soft as wax, but regains its hardness and elasticity on cooling. If it is raised above 300° F. decomposition sets in, accompanied by complete opacity and spontaneous combustion, yielding a heavy smoke. When exposed to very low temperatures it becomes hard and brittle, and loses its elasticity, but at ordinary temperatures it is quite inert, and retains all its properties without any change.

It is quite insoluble in water, and is therefore largely used for vessels employed in photography, and for surgical purposes, such as basins, syringes, and other appliances. Even sea-water does not affect it, and recently experiments have been made with some success by using successive coats of celluloid varnish as an anti-fouling paint on the hull of iron ships, which not only appears to adhere well, if the steel plates have been properly cleansed before the successive coats of varnish are laid on, but seems also to protect the bottom from the attachment of barnacles. It is attacked by alcohol, in contact with which it swells up, and when ether is added it dissolves in the mixture. Sulphuric and nitric acid dissolve it without leaving any residue, and it is therefore little used for chemical apparatus.

Although, when first made, it always retains a smell of the camphor, yet when permitted to remain for some time in a moderately warm atmosphere this passes away; and where this smell is objectionable the mixture of the celluloid with other non-aromatic substances, and especially where transparency is not necessary, renders it almost without smell.

Uses of Celluloid. In one form or other celluloid is now extensively used for an endless variety of purposes, such as umbrella and walking-stick handles, toilet and handkerchief boxes, billiard balls, setting for artificial teeth, combs and brush handles, and all classes of imitation ivory and tortoiseshell ware, such as purses, cigar-cases, pocket-books, etc. The fact that it can be made plastic by heat and regains its hardness when cooled renders it specially useful where embossing, inlaid metallic ornamentation, and filigree work are required, and also for mosaics which rival ivory and marble in beauty. In addition to he above, celluloid is now largely used in the preparation of clichés in printing, which are far more sharp in the outline and more durable in working than those made from other materials. When mixed with zinc, white oxide of manganese, or chalk, it is also used in the manufacture of collars and cuffs, and can be made to imitate the exact appearance of linen, and when these are covered with a solution of celluloid varnish the surface, while retaining apparently the grain of the cloth, is rendered sufficiently smooth to enable them to be sponged with soap and water and so rendered perfectly clean after wearing, and the durability is far greater than linen. The same varnish or lacquer which is used for the coating of these articles can also be used for other purposes, where a varnish is required, and is much more elastic and durable

than those made from resin or gum, and affords a perfectly waterproof surface and a protection to polished metallic and other surfaces liable to oxidation.

Specially prepared varnishes made from celluloid solutions poured on to a smooth surface such as a glass plate form, when the solvent has evaporated, the photographic films for the cinematograph and for use in the camera.

Preparation of Celluloid.—The basis of the celluloid preparations is the soluble nitro-cellulose, which, as prepared for the manufacture of collodion, consists of the lower non-explosive nitrates, such as the mixture of the tri- and tetra-nitrates, which are completely soluble in ether-alcohol.

When the nitrate has been prepared there are two processes which can be used in the mixing of the nitrate and camphor, viz., the dry and the wet processes, each of which has both advantages and disadvantages, but the wet process is the one now more usually adopted, as it is safer and requires less expensive machinery for the after manipulation.

1. *In the dry process*, after the nitro-cellulose is made and washed, it is slowly dried at a temperature sufficiently low to prevent explosion, until the cotton contains not more than about 20 to 25 per cent of water. The cotton is then reduced to a viscid pulp in a suitable reducing machine, and the mass mixed with camphor in a fine state of division, in the proportions of from 40 to 50 parts of camphor with 100 parts of the nitro-cellulose. The mixture is then worked or kneaded in a suitable machine until the two are thoroughly impregnated. The mass is then subjected to pressure either enclosed in strong bags, the same as are used in expressing the oil from seed, placed between hot plates so as to remove any excess of water, or the mass is placed in a jacketed cylinder, the piston of which is a hydraulic ram, and the celluloid, heated

by the steam jacket and squeezed by the ram of the press, parts with the larger part of its water, and when dry exhibits the appearance of a transparent soft mass of celluloid which can be rolled into sheets, pressed into moulds, or retaining its cylindrical form be turned or cut into any required shape.

During the whole of this process the utmost care must be exercised that the temperature is not allowed to rise too high, and that the whole of the nitro-cellulose has been completely incorporated with camphor, as, if any of the nitro-cellulose remains uncombined, there is danger of explosion, and specially during the after heating process which is employed to drive off any excess of the solvent, camphor, or water. To secure that the change in the nitro-cellulose has been complete, it is usual to allow the kneaded mixture to stand some hours in a closed vessel. until the action of the camphor upon the nitro-cellulose is complete, before the final pressing and drying.

2. *The wet process*, which is the better and safer of the two, may be thus generally described. The soluble nitro-cellulose, prepared the same way as for the manufacture of collodion, must be completely dried in a current of warm air, and care must be taken that this temperature is never allowed to rise above that of boiling water. A mixture is then prepared of 100 parts by weight of ether, and 5 parts by volume of alcohol of ·0728 sp. gr., with 28 parts by weight of camphor. Either methyl or ethyl-alcohol may be employed, as the camphor and nitro-cellulose are soluble in either. This solution is then placed in earthenware or stone-ware jars and the dry cotton stirred into it, in small quantities at a time, until 50 parts by weight of the cotton, in relation to the whole weight of the camphor solution, has been reached, when the mixture will become a clear

gelatinous mass. If the celluloid is intended for articles or varnish which must be absolutely clear, and transparent, it is essential that the nitro-cellulose must be perfectly soluble, and samples must be tested of each batch of the cotton when it is dried, to make sure that this is the case before being stirred into the mixture. On the large scale steel or wrought-iron vessels, tinned inside so as to prevent the contents from being contaminated with the iron, may be employed, and mechanical stirrers used to keep the mass in agitation until complete solution is attained. If the least milkiness is observed, the solution, unless to be used for dense objects and in combination with filling materials which are to be worked into it, must be filtered, but as this is a difficult process to accomplish satisfactorily it is much better to be quite sure that the cotton is perfectly soluble by careful testing before mixing. In some cases, and where the celluloid is to be used for the coarser articles, so as to avoid danger from explosion by the complete drying of the cotton, it is used with a certain amount of water still retained in it, and although the complete solution is obtained the presence of the water becomes a serious difficulty when the mass has to be treated so as to drive off the solvent and obtain the celluloid as a transparent solid. The difficulty arises from the great difference in the evaporating point of the ether, alcohol, and water. Pure ether boils at 96·8° F., absolute alcohol at 172·4° F., and water not until 212° F.

The drying presents many points of difficulty because, as the process proceeds and the mass becomes more viscid, bubbles of escaping gas are apt to form cavities in the celluloid, which spoil its transparency and homogeneity. The moisture, which the celluloid parts with last, is the most deleterious in this respect, as it is not given off

in any quantity until the ether and alcohol are driven off. To get over this difficulty it is best to dry the cotton, but even then there is always more or less water associated with the alcohol, and the usual process is therefore, when the bulk of the solvent has evaporated and the material assumed a fairly solid consistency, to cut or roll it into thin sheets so as to present a large free surface for the solvent and water to evaporate from, and the sheets are left for a time in a warm atmosphere, and then consolidated by passing between rollers, which for many purposes are warmed so as to make the celluloid more plastic. To save as large a portion of the alcohol and ether, which is used as the solvent, the mixing and dissolving chamber is connected up to a condensing apparatus, and when the time for the elimination of the solvent arrives, when the ultimate commingling of the cellulose with the camphor solution is complete, a current of warm air is drawn through vessel and condensing apparatus, and this carries the vapours of the solvent along with it, and when condensed the recovered ether and alcohol can be used over again. Another and perhaps a better method is to dispense with the alcohol altogether, and to use anhydrous ether alone as the solvent, and then the difficulty of the variation in the temperature of the boiling-point is avoided, and so danger from air-bubbles is almost entirely eliminated, since there is no water present in the resulting gelatinous mixture, as the nitro-cellulose is also dried until practically anhydrous as well as the ether. Unless care, however, is exercised there is great danger from the possible mixture of the ether vapour with air, where even when small quantities of the ether are present, an explosive mixture is formed. This difficulty is overcome by working the process under a slight vacuum, in which case there can be no escape of the vapour

of the ether, which is carried forward into a closed condenser, and the ether is recovered by condensation in a properly constructed worm. The drying of the mass is easily conducted by placing the celluloid, when in the viscid condition, in shallow trays divided into compartments, each of which contains just the necessary quantities for a sheet of celluloid in the manufacturing process. These trays are then placed in an oven, through which a current of air is drawn in such a manner that it passes over the surface and beneath the trays, and thus the evaporation of the ether is accelerated and the vapour carried into the condenser for recovery. If care is exercised in this process there is no danger whatever, and the results are the production of celluloid of the very highest grade, and freed from bubbles or any other defects. The celluloid produced by this process is, when taken from the drying chamber, not quite so solid as that produced by the ether-alcohol mixture, but by rolling it can be brought to any required degree of density. The rolling is best conducted after the drying process is complete, and if the mass has attained too great a hardness this can be remedied by passing more highly heated air into the drying chamber having a temperature of about 150° F., which will give the celluloid the required degree of plasticity; and if the nitro-cellulose has been of the perfectly soluble character and the camphor of the proper quality the texture will be perfectly colourless and homogeneous. The sheets are best made as thin as is convenient so as to allow the last remainder of the solvent to escape as easily as possible, and these can easily be rolled together when in the plastic state so as to form a single sheet of any required thickness, as under pressure the amalgamation of the surfaces is perfectly complete, no lamination being visible after the welding.

By this process it is possible to recover the largest portion of the ether for use again.

When the celluloid is to be used for the purposes of varnish it can be removed from the mixing chamber as soon as the solution of the cotton is complete, and mixed with a further portion of any required solvent so as to give it the consistency which is required. This avoids the expense and necessity for re-dissolving from the solid celluloid.

Where the celluloid is to be mixed with other bodies so as to give it a solid opaque condition, this is best done by mixing when the mass is in the gelatinous condition.

In the same way, when the mass is to be coloured, and a large quantity to be of one uniform colour, the colouring matter is best mixed when the mass is in the gelatinous condition. The best colouring matters are the aniline and coal-tar dyes, which are soluble in alcohol, and can be obtained of any required shade. Where a large variety is required the finished articles may be immersed in the dye, which is readily absorbed by the celluloid; and when the degree of colour desired is obtained the surface can be polished, and if necessary covered with a new coating of transparent celluloid varnish. Although, when perfectly pure and transparent celluloid is required, the cotton cellulose is always employed in the making of the nitro-cellulose, yet where these various properties are only required in a moderate degree, cellulose from any other source, such as wood pulp, may be employed, if cheaper than cotton, but care must be exercised to see that they are perfectly purified from any resinous or other foreign materials which will prevent the action of the camphor.

In the same manner other solvents, besides ether-alcohol, such as acetone, amyl-alcohol (fusel oil), benzene, etc., have

CHAPTER VIII

CHEMISTRY OF THE COTTON FIBRE—*continued*

Artificial Silk or Lustra-Cellulose.—Solutions of cellulose in one form or another are now largely used in the production of fibres which rival in lustre the real silk obtained from the silk-worm, and the production of this artificial silk has now become a large and increasing industry in England, France, Germany, and Switzerland, and the United States. Originally the basis of this silk was always the soluble nitro-cellulose, and this was used by the inventor, M. de Chardonnet, a French chemist, as early as 1884, and although there are now several other processes of which the base is either viscose, celluloid, or a solution of cellulose in zinc chloride, the credit of the foundation of this industry must always remain with M. de Chardonnet, because he not only invented the process but also the necessary machinery to enable the artificial silk to be manufactured, whatever the source from which the threads are derived.

"Chardonnet's" Process.—The nitro-cellulose used must always be of the completely soluble form, *i.e.* the mixture of the tri- and tetra-nitrates, prepared as already described in the manufacture of collodion. As a rough test apart from any chemical examination M. de Chardonnet

employed polarised light in examining the nitrated cotton under the microscope, when, if the nitrating process is complete, the fibres appear of a uniform pale blue colour.

After the nitrated cotton has been freed from the superfluous acid mixture by means of pressure, hydraulic or otherwise, the resulting mass is treated in a hollander until all the acid is completely removed, the acid as far as possible being recovered and re-concentrated for use over again. The washing process is one of the utmost importance, as any traces of acid which might remain would interfere with the complete solution of the nitrate in the solvent. In this process, which usually occupies about twelve hours, it is found that about ten gallons of water are required for every pound of the nitrate.

The washed nitrate is then treated in a press or centrifugal hydro-extractor to remove the excess of water until it contains about 33 per cent, and in this state it can be stored with perfect safety until required for use, care being always taken to prevent contamination by dust or other mechanical impurities.

The nitrated cotton is then dissolved in a mixture of equal parts of 95 per cent alcohol and ether, and for complete solution 100 quarts of the solvent are required for every 50 pounds of dry nitro-cellulose. While the cotton is being dissolved the contents of the vessel in which the solution is being conducted must be kept in a state of continual stirring so that the cotton and solvent are brought constantly into intimate contact until the solution becomes perfectly clear throughout. Even when every care has been taken it will always be found that there are some undissolved particles floating in the viscid solution, and these must be entirely removed and the

solution made absolutely free from any mechanical impurities, or it cannot be forced through the orifices in the after formation of the threads. On the large scale the solution of the cotton is usually made in iron or steel vessels heavily tinned inside to prevent contamination with iron, and fitted with mechanical agitators, which are kept in constant slow motion until the operation is complete. The absolute necessity that the gelatinous solution must be free from any mechanical impurities requires a filtering process which is by no means easy to accomplish with such a viscid fluid. The filter usually consists of a strong iron vessel, heavily tinned inside, with a lid which can be made gas-tight, and the whole sufficiently strong to stand a pressure of 1000 pounds per square inch. This vessel, which usually has a capacity of about 25 gallons, is connected up to an air-compressor, so that when the vessel is filled with the viscid solution any required pressure may be employed to force it through the filtering medium. The filter, which is placed in the bottom of the cylinder, consists of a layer of fine cotton wadding about 0·5 in. thick, which is covered on each side by a sheet of the finest silk gauze, and to give it rigidity the two sides are then enclosed by a layer of fine metallic gauze, which is also tinned like the interior of the vessel. This filter is placed on suitable supporting bars at the bottom of the vessel, but leaving room beneath for the filtered colloid solution to filter into and pass out by an appropriate orifice. It is sometimes necessary to repeat the filtration even more than once so as to remove even the smallest particles of undissolved cotton, and this must be done as often as necessary, until the solution is absolutely pure.

The filtered solution is then allowed to stand for some days in glass carboys until the viscid collodion has attained

perfect uniformity of density in every part, as this is essential if the fibres which are to be made are to be of uniform strength and elasticity. The spinning machine is a very ingenious apparatus, and may be described as follows. The viscous collodion is placed in a vertical steel cylinder, tinned inside, and connected by a pipe up to the air-compressor. A strong tube connected with the bottom of the cylinder has a number of small tubes screwed into it horizontally, which terminate in glass nozzles, having each a fine capillary orifice only just the diameter of the thread which is to be produced. These nozzles are arranged about three-quarters of an inch apart. The nozzles are surrounded almost up to the point where the orifice opens by a case or outer tube forming a jacket, through which hot water can be circulated so as to increase the fluidity of the solution, and to prevent the orifices clogging up. The necessity for the perfect filtration of the collodion is now apparent, because the small capillary orifice, which usually does not exceed $\frac{1}{800}$th part of one millimetre in diameter, would be filled up, and the continuity of the thread broken by the smallest particle of foreign matter, necessitating the stopping of the machine. The pressure of the air on the top of the collodion in the cylinder forces it down the pipe and out of the glass nozzles in a continuous fine stream, which hardens into a thread as soon as it passes into the air by the evaporation of the solvent. These threads are then caught up and wound on to a reel. Usually several of the threads are wound together.

Sometimes a trough is placed beneath the row of nozzles, and a fine stream of water plays on to each thread as it emerges from the orifice, so as to hasten the hardening process and wash the solvent from the surface of the thread.

This is, however, said to injure the lustre of the thread, although it is found slightly to increase its tenacity.

The pressure and flow of the viscous collodion required careful adjustment, so as to make a perfectly uniform thread, and the speed of the winding reel must be exactly adjusted, so as not to subject the thread to a greater tension than it will bear without breaking. In the machine devised by M. de Chardonnet these adjustments are overcome with great ingenuity, and are made automatic, so that the process can be carried on continuously. The whole of the spinning part of the machine is enclosed in a glass case, which can be opened when necessary. The case is connected with a condensing apparatus, and through the case and condenser a stream of warm air is aspirated, which carries along with it the vapour of alcohol and ether from the drying threads, which is condensed and used over again. The thread, as it comes from the spinning machine, is highly inflammable, for although it contains a quantity of water which was associated with the nitro-cellulose before dissolving in the solvent, yet a quantity also evaporates along with the solvent in the formation of the threads.

This great inflammability of the artificial thread at first was one great bar to its use, but now the difficulty is got over by a process of denitration similar to that employed in rendering celluloid non-inflammable. This is accomplished by passing the thread, after it has hardened, into or through a solution of an alkaline sulphide, usually ammonium sulphide, though others may be substituted. Ammonium sulphide does not seem to attack the surface of the thread or destroy its lustre as much as that of potassium or sodium. This solution is usually prepared by passing sulphuretted hydrogen through a concentrated solution of ammonia until the point of saturation is complete, and

allowing it to stand until the solution turns yellow by the formation of various polysulphides which are particularly active in the denitration. The exact nature of the reaction is not yet known, but it seems to reduce the nitro-cellulose to some form of hydrate of cellulose, which is less inflammable than the nitro-cellulose. The proper strength of the solution and the exact temperature at which the operation is best carried on are of the utmost importance, and are usually determined by each manufacturer for himself, as they appear to vary to some extent by the nature of the source from which the cellulose is derived being different for that of wood-pulp as compared with cotton.

If the solution is too strong, the lustre of the fibre is destroyed, but this can easily be ascertained by examining the fibres with reflected light under the microscope, and the denitrating process is accelerated by an increase in temperature, up to a point, beyond which the solution attacks the fibres as above, even if the strength is not too great.

Since the Chardonnet process came out various attempts have been made to introduce improvements into the process, either by the introduction of other materials along with the nitro-cellulose or by the use of a different solvent, or by a variation in the process of manufacture. Two of these, viz. the process of Du Vivier and that of Lehner, are the most important.

The Du Vivier process employs the same soluble nitro-cellulose, viz. the tri- and tetra-nitrates, but he uses a different method of nitration by having a mixture of dry saltpetre and sulphuric acid in place of the nitric and sulphuric acid mixture, in which there appears to be no advantage. Also in place of the usual solvent for collodion, the ether-alcohol mixture, he employs a highly concentrated

glacial acetic acid in the proportion of one hundred parts of the acid by weight to seven parts of the nitro-cellulose, and with the viscid solution obtained he mixes a certain proportion of isinglass and gutta-percha. After the thread is spun in the same way as employed by Chardonnet, the fibres are passed through a bath containing various metallic salts, such as the salts of alumina, the object of which is to render the isinglass insoluble. The fibre is then denitrated in the usual manner. The threads produced by this process have a high lustre and considerable strength, but so far the manufacture does not appear to have been attempted on a large commercial scale.

Lehner silk is made also from the soluble nitrates; but he adds to the collodion so obtained a solution of natural silk obtained by dissolving silk waste in glacial acetic acid. He also adds a certain amount of sulphuric acid to the solution, by means of which the collodion mixture is kept in a more limpid condition, and can be forced through the spinner orifices with considerably less pressure, which is an advantage. Unless the threads are afterwards completely cleansed from the sulphuric acid their strength will be deteriorated in process of time. This is by no means easy to accomplish, because the acid is incorporated with the substance of the thread as well as on the surface, and so resists every process of washing except prolonged soaking. Sometimes, in place of silk solution or in combination with it, he adds a solution of a rubber prepared from drying oils. Unlike Chardonnet, who when the threads emerge from the orifice allows them to evaporate the solvent and consolidate in the air, Lehner passes them through a solution, consisting of a mixture of turpentine, chloroform, and juniper oil, and then hardens them by treating them with a solution of sodium acetate, after which the threads are

denitrated in similar manner to that employed in the Chardonnet process.

Denitrating Process.—Although the method employed by Chardonnet renders the fibres much less inflammable, yet unless the greatest care is exercised and the exact strength of the solution and the temperature of the working ascertained the lustre is to a certain extent dimmed. In order to obviate this, H. Richter[1] made a series of investigations regarding denitration, and according to his method he asserts that the lustre is unaffected. His treatment consists in acting upon the threads with such metallic salts as have lower and higher degrees of oxidation, the solutions of the lower degree being used with the addition of an acid – only sufficient acid, moreover, being taken to convert the lower into the higher degree of oxidation. Amongst the metallic salts he found the cuprous compounds to be the most suitable, and specially cuprous chloride and oxychloride, by means of which complete denitration was effected. In addition to cuprous compounds he found that there might be used, either separately or in mixture, ferrous, manganous, chromous, tungstous, and mercurous salts, and the ferrocyanides and metallic cyanide combinations. He found also that the denitrating process was accelerated by the addition of substances which caused the threads to swell up and thereby become more porous and receptive to the denitrating solutions; and in addition to a certain proportion of alcohol and ether he found, as being suitable for this purpose, oil of turpentine, glycerine, indifferent hydrocarbons and their derivatives, rubber solutions and more especially isinglass, which seems to confirm the rationale of Du Vivier's process. Such additions, he asserts, cause the denitration to take place with greater regularity and

[1] *Cellulose*, by Dr. Joseph Bersch, London, 1904, p. 225.

smoothness, and without injury to the lustre or strength of the thread. The disadvantage of the use of nitro-cellulose remains, however, in all these processes, viz. its explosive character, and the fact that to mitigate this, denitration is required, and even then comparatively great inflammability remains. It is not surprising, therefore, that attention is being directed to those solutions of cellulose which are obtained direct, and not from the nitro-compounds but from those derived from the action of alkalies and alkaline salts rather than from the use of acids.

Artificial silk prepared from the thiocarbonate of cellulose, which is obtained from the action of strong caustic soda upon cellulose, and then the resulting product dissolved in the bisulphide of carbon, has already been manufactured; but hitherto its use has been confined to the manufacture of coarse threads which closely resemble structureless horsehair, and are used in the manufacture of hair-seating and other similar fabrics.

The many advantages, however, to be obtained by the use of these direct cellulose solutions seem to indicate that they will in the future play an important part in the evolution of the textile industries.

Hydrofluoric acid has a remarkable action upon cellulose, inasmuch as it forms along with it a tough waterproof material which does not, however, resemble the paper parchment obtained by the action of strong sulphuric acid, since it is much tougher, and possesses very high electrical insulating properties; and a material prepared in this way is now being used when solidified for electrical purposes, and also when in the colloid state, in the manufacture of the carbon filaments for the electric light in place of the preparations made by the zinc chloride process.

Action of Organic Acids upon Cellulose.—By

organic acids such as tannic, tartaric, citric, and oxalic acids, cellulose is but slightly attacked even when in a concentrated state; the action of oxalic acid being, however, the most energetic, and with this it forms compounds which however, have not been fully investigated.

Tannic acid exhibits a much greater affinity for cellulose than the others, and indeed cellulose will absorb from 7 to 10 per cent of its weight from aqueous solutions without injury to the fibre, and this action is taken advantage of in the mordanting of cotton in the dyeing and printing of basic colours.

The non-volatile organic acids, such as oxalic, tartaric, and citric acids, when allowed to dry on the fibre act upon it almost in the same way as mineral acids, and especially at an elevated temperature and with a dry heat have a weakening action upon the strength of the yarn or fabric. This is most important, and especially as they are largely used in calico-printing. Experiments were made by printing calico with a paste containing 20 grains per litre of oxalic acid, and an equivalent amount of other acids, and these were first exposed for four hours to an ordinary temperature, and in the second case were steamed for one hour. The following table exhibits the results of this weakening action:—[1]

Acid.	I.	II.
Oxalic acid	25 per cent	25 per cent
Tartaric acid	5 ,,	10 ,,
Ortho-phosphoric acid	1·5 ,,	15 ,,
Meta-phosphoric acid	31·5 ,,	35 ,,
Pyro-phosphoric acid	35 ,,	35·5 ,,
Phosphorous acid	27 ,,	28 ,,

[1] *Textile Fibres*, by Matthews, London, 1907, second edition, p. 227.

Sulphocyanic acid, under similar conditions, tenders the fabric very slightly, but under the influence of hot air the action is greater even than with oxalic acid. Matthews[1] appears to think that the destructive action of these acids in the cotton fibre is not so much the chemical action as a purely mechanical result arising from the acids crystallising within the lumen of the fibre, and thus breaking it up by simple rupture.

Oxalic acid appears to have a peculiar effect upon cotton, inasmuch as if a piece of cotton cloth is printed with a thickened solution, dried, and after being hung in a cool place for about twelve hours and then well washed, so as to remove the solution from the parts of the cloth which have been printed with the oxalic acid, it exhibits a direct affinity towards basic dyes, while towards substantive dyes it exhibits considerably less attraction than ordinary cotton, but is partially reactive with the alizarin dyes. Tartaric and citric acids do not produce this effect, nor does neutral or acid potassium oxalate.

With acetic, butyric, and similar acids cellulose forms a series of combinations which have the character of esters; that is, they are formed by the substitution of a hydrocarbon radicle for the hydroxylic hydrogen in the acid, which is analogous to those obtained by the action of nitric acid.

Although cellulose will not react at ordinary temperatures with acetic anhydride, yet, according to Cross and Bevan,[2] where cellulose and acetic anhydride are heated to 380° F. in a sealed tube in the proportion by weight of seven of cellulose to six of acetic anhydride, the cellulose is converted into a triacetate having the formula $C_{12}H_{14}O_4(OCOCH_3)_6$. With the reagents in the proportion

[1] *Textile Fibres*, by Matthews, London, 1907, second edition, p. 227.
[2] *Cellulose*, by Cross and Bevan, London, 1895, p. 35.

of one to two a mixture of lower acetates is formed. The latter are insoluble in glacial acetic acid, while the triacetate is freely soluble. The solution is highly viscous, and can only be filtered with difficulty unless diluted with benzene. This acetate also dissolves when heated with nitrobenzene, and the solution gelatinises on cooling even when highly dilute.

Cellulose acetates are easily saponified by dilute solutions of alkaline hydrates, and specially in the presence of alcohol.

In the presence of relatively small quantities of zinc chloride cellulose and acetic anhydride react at a temperature of from 262° to 280° F., forming a triacetate, and if the temperature is increased the acetylation proceeds further, and higher acetates are obtained.

The following table shows the quantitative relationship of the higher acetylated derivatives of cellulose, with the percentage of carbon and hydrogen, and the yield of acetic acid and cellulose as given by Cross and Bevan :—

Name.	Formula.	Temperature.	C.	H.	Yield on Saponification.	
					Acetic.	Cellulose.
Triacetate .	$C_{12}H_{16}O_8$	288° F.	50·0	5·5	62·1	56·2
Tetracetate .	$C_{14}H_{18}O_9$	330° F.	50·6	5·6	72·7	49·1
Pentacetate.	$C_{16}H_{20}O_{10}$	372° F.	51·6	5·3	80·6	43·2

The tetra-acetate of cellulose, of which the formula may be expressed $C_6H_{10}O_5(C_2H_3O)_4$, is of peculiar interest. It is perfectly insoluble in methyl and ethyl alcohol, ethyl and amyl acetates, acetone, and ether, but is soluble in ethyl benzoate, chloroform, glacial acetic acid, and nitrobenzol. The latter solution congeals on cooling to a solid

and perfectly transparent jelly. If a solution of this acetate is poured upon a glass plate and allowed to remain until the solvent has evaporated, there remains behind a thin film of great transparency and tenacity.

This is much more resistant to the action of chemicals than the products derived from nitro-cellulose, and indeed is not attacked by alkalies even at high temperatures. Prolonged boiling with strong caustic soda, however, will finally destroy the combination, and leave behind it a transparent film of pure cellulose. The most remarkable property of this acetate is its great electrical insulating properties, surpassing in this respect both rubber and gutta percha. It is perfectly non-inflammable, and only softens at a temperature of 300° F., and in itself or some modification appears to be specially adapted for electrical works, and particularly as it retains its elasticity, and is not liable to break with a moderate degree of flexure.

The fact that it is neither explosive nor inflammable makes it useful for a variety of purposes where neither collodion, celluloid, nor any derivative of nitro-cellulose can be used either in solid or as a varnish. It is perfectly odourless.

Solid spirit or solidified alcohol is made from cellulose acetate. This body is prepared by dissolving 100 grammes of cellulose triacetate in 500 grammes of glacial acetic acid and pouring the mixture in 2 litres (2·113 quarts) of alcohol. Cylindrical structures of a gristly nature are formed in the vessel, from which the excess of glacial acetic acid and alcohol can be removed by pressure. These cylinders are then dried in warm air, and can be kept in closed vessels until used. When heated the product does not melt, but when ignited they burn away without leaving any residue.

3. Action of Alkalies upon Cellulose.—Unlike

acids, which, even when dilute, have such an injurious action upon cellulose, alkalies are harmless under ordinary conditions. If the air is excluded, neither carbonated nor caustic alkalies, even at a boiling temperature, attack it. If, however, air or oxygen is present, the case is different and especially where a high temperature is employed, as the alkalies act in the same manner as acids by causing hydrolysis, and thus the cellulose molecule is broken up and the tenacity of the fibre is destroyed proportionally to the extent of the reaction.

This action is of the utmost importance, because of the use of the alkalies to remove from the cotton fibre the grease or wax which is always associated with it in the natural condition, and which it is essential should be removed before the process of bleaching or dyeing. This is specially important in the case of bleaching, because the temperature and pressure are higher in the kiers than in ordinary dye-vats, and at high pressure the action of alkalies becomes destructive to the fibre by forming soluble products along with them, the extent of which depends on the pressure, and therefore also on the temperature of the solution as well as the strength of the solution.

Tauss made a series of experiments to determine the extent of this action, and the following table gives the results :—

Pressure.	Strength of Solution. 3 per cent Na_2O.	Strength of Solution. 8 per cent Na_2O.
	Percentage of Cotton dissolved.	
15 lbs. per square inch	12·1	22·0
75 ,, ,,	15·4	58·0
150 ,, ,,	20·3	59·0

Ammonia has no action upon cotton at ordinary temperatures, but if the temperature is raised under pressure to above 420° F. there is a reaction which results evidently in the formation of an amido-cellulose or celluloses, and the product acquired a much greater affinity for acid colouring matters. The action of cellulose with gaseous ammonia is very remarkable, as it possesses the power of occlusion to a very amazing extent, being able to absorb at the ordinary atmospheric pressure 115 times its own volume. The author found that it also absorbed many times its volume of oxygen. This is similar to the power possessed by bone charcoal or spongy platinum, but whether the cause is the same or not is not certain. They all seem in certain cases to possess the power of precipitating metallic oxides from their solutions, which, from analogy with the platinum, would seem to indicate that the action is mechanical rather than chemical, possibly osmotic.

Strong Caustic Soda.—When cellulose in the form of cotton fibres is treated with concentrated alkali, such as caustic soda, it undergoes a remarkable change, both mechanically and chemically. The fibres swell up and thicken, and the tensile strength is increased, and it acquires greater absorptive power and affinity for dyes.

This remarkable action was first observed by Mr. John Mercer of Accrington in 1850, and upon it is founded the process known as "mercerising" from its inventor, and which will be fully described in the next chapter.

This change in the character of the cellulose after treatment with strong alkali is due to a definite reaction between them, resulting in the formation of a new compound having the molecular ratio $C_{12}H_{20}O_{10} . 2NaOH$, accompanied by combination with water. This compound is

decomposed on washing with water, the alkali being recovered unchanged, and the cellulose remaining as the hydrate, $C_{12}H_{20}O_{10} . H_2O$.

If treated with alcohol in place of water one-half of the alkali is removed, and the reacting groups remain associated in the ratio $C_{12}H_{20}O_{10} . NaOH$.

Recently this reaction has acquired great importance, because upon it is now founded the manufacture of viscose and viscoid, which have a very important technical application. The process upon which this manufacture is founded is described as follows by Cross and Bevan.

When an alkali-cellulose (hydrate) is exposed to the action of carbon disulphide at ordinary temperature, a simple synthesis takes place, which may be formulated by the typical equation—

$$X . ONa + CS_2 = CS \begin{cases} OX \\ SNa \end{cases}$$

The best condition for the reaction appears to be when the reagents are brought together in the molecular proportions $C_6H_{10}O_5$ 162, $2NaHO$ 2×40 80, CS_2 76, $(30 - 40\ H_2O)$

the second ONa group being in direct union with the cellulose molecule, which reacts, therefore, as an alkali cellulose. The resulting compound is, therefore, an alkali-cellulose-zanthate. This substance is perfectly soluble in water, with which it forms a solution of extraordinary viscidity, and hence it is termed viscose.

The course of the reaction by which it is produced is marked by the further swelling of the mercerised fibre

and gradual conversion into a transparent gelatinous mass, which dissolves to a homogeneous solution on treatment with water. The most characteristic properties of these cellulose zanthates are their spontaneous decomposition into cellulose, hydrate, alkali, and carbon disulphide, and their coagulation by heat, when the solution is evaporated at a low temperature, into a dry solid, perfectly re-soluble in water.

If heated at 158° to 176° F. the solution thickens, and at 194° F. the coagulation is rapidly completed.

If the solution is dried down at this temperature in thin films they adhere with great tenacity to the surface upon which they are dried. They can be detached by treatment with water; and when freed from the products of reaction the cellulose is obtained as a transparent sheet of great toughness, which on drying hardens and increases in toughness, while still retaining a high degree of elasticity.

By heating the thiocarbonate obtained as above with sulphurous acid in sufficient proportion to combine with one-third of the alkali, regenerated cellulose may be obtained, but it differs from the original cellulose inasmuch as it contains a higher percentage of water (9 or 10), and the composition in percentage yields $C = 43 \cdot 3$ per cent, $H = 6 \cdot 4$ per cent, which corresponds to the formula $4C_6H_{10}O_5 . H_2O$.

This form of cellulose is acetylated merely by heating it along with the acetic anhydride at its boiling-point, whereas normal cellulose requires a temperature of 388° F.

Viscose.—In the manufacture of viscose it is necessary to have the cellulose in as fine a state of division as possible, because it is advisable that the soda compound should be formed quickly, and this is hastened by the cellulose fibres being cut up or ground into small pieces, so that the soda solution may act on as large a surface as possible at once,

and also be able to penetrate into the interior of the cells with the greatest facility.

In order to accomplish this the fibre is usually worked in a hollander, set fine, as is employed in making the material for blotting-paper, so that the staple may be as short as possible. The cellulose must be perfectly pure and free from foreign matter if the viscose is to be of the best quality, and specially if intended for making viscose filaments.

The amount of water contained in the cellulose mass is very important, because, as the alkaline ley with which it has to be treated in the mercerising process only acts when of a certain strength, the water associated with the cellulose must be taken into account along with the water which has to be added to the ley.

It is usual, therefore, after the cellulose has been prepared in the hollander and exists as a fine creamy pulp, to dry it in air, until it does not contain, associated with it, more than 50 per cent of water. Before drying, the excess of water is removed by passing the pulp through a centrifugal hydro-extractor.

As soon as the cellulose pulp is ready, and its water content ascertained, it is transferred to a machine similar to that used in a paper-mill for breaking up what is termed "half-stuff," and worked until all parts are loose and the large masses broken up. The preliminary working is always necessary when the cellulose has been prepared for some time before the mercerising process.

The caustic soda solution must be prepared of a sp. gr. of 1·2 to 1·4, and although the proportion to be used with a given quantity of the cellulose pulp may vary, it is found in practice that the best is fifteen parts of caustic soda to thirty parts of the air-dried cellulose. Excess of soda

beyond that required to effect the mercerisation is of no advantage, and requires to be removed afterwards, although some manufacturers prefer to use an excess, and then remove and concentrate for use over again.

The soda ley is slowly admitted to the cellulose pulp as it is being worked, and when the whole has been added the mixture is diluted with sufficient water added slowly, to bring up the total water content to 50 per cent, including that associated with the cellulose already, which must be previously ascertained.

Care must be taken not to fill the machine too full with the pulp previous to adding the soda ley, because the action of the soda causes, as the action proceeds, the mass to swell considerably, and thus the volume in the machine is largely increased. There is also a considerable increase in the temperature, which is, however, kept down, and can be regulated by the addition of the water, and when the water contents of the cellulose itself are not too large this can easily be done. The conclusion of the action is marked by the mass becoming of a granular condition not unlike crumbled bread. After removal from the mercerising machine the product is passed through a fine sieve with meshes not larger than $\frac{1}{5}$ of an inch square, and unless the product is going to be further treated as soon as cold, to be further changed into viscose, it must at once be stored in air-tight tanks, as it rapidly undergoes change by absorption of carbonic acid from the air, and this rapidly deteriorates its quality for the manufacture of viscose. The question of temperature is of the utmost importance also, as although most of the chemical change has occurred in the mercerising vessel, still, if the produce is stored, a further generation of heat takes place which indicates that the reaction continues for some time. The

storage vessels must be made of iron, and perfectly air-tight, and they must have some arrangement by which the pulp within can be reduced to and kept at a temperature not exceeding 43° F. On the large scale a refrigerating machine may be employed and the storage vessels cooled either by being jacketed or having internal encirculating tubes, so that the temperature can be carefully observed and regulated. If the temperature is allowed to rise much above 50° F. it rapidly causes decomposition, and becomes unfit for use. The decomposition is accompanied by the formation of acetic, formic, and lactic acids and their cellulose compounds.

Preparation of Viscose.—The viscose solution is obtained by mixing the soda-cellulose prepared as above with carbon disulphide in the proportion of ten parts of the cellulose to one part by weight of the disulphide. The mixture must be made as rapidly and intimately as possible. Vessels of wood must be employed, as the disulphide frequently contains impurities such as free sulphur, which would attack metal. A wood vessel arranged like a churn with revolving paddles is usually employed, and must be absolutely gas-tight, as the carbon-disulphide is a very volatile body, with a most disagreeable odour, and highly inflammable when it burns into sulphurous acid. It also forms, when in the state of vapour, a highly explosive mixture, so that the greatest care must be taken to prevent naked lights being used, and indeed it is better for this process to be carried out in a well-ventilated place and only during daylight. The mixture must be made in the cold, and with a temperature of about 60° F. complete emulsification takes place in about half an hour. The temperature must never be permitted to rise above 90° F.

When the change is completed it results in the formation of cellulose sulpho-carbonate.

Before the mixing machine is opened so as to permit the viscose to run out, it is necessary to remove the smallest excess of the disulphide of carbon which remains in the vessel uncombined. This is done by connecting up the vessel to a suitable condensing apparatus, into which the disulphide vapour is drawn by the opening of a vent in the top of the vessel, and aspirating air through it. A slight vacuum is therefore caused in the mixing vessel, and the disulphide vapour is drawn through the worm of the condenser and recovered for future use.

In this process the greatest care must be exercised, as the mixture of disulphide of carbon and air is very inflammable and explosive; naked lights must not be used, and it is better to conduct the process only during daylight.

Preparation of Viscose Solution.—The contents of the mixing vessel after the carbon-disulphide has been removed are then drawn off into another vessel also fitted with a mechanical stirrer, and when this is set in motion water is slowly added. The viscid mass swells up and rapidly assumes the consistency of a thick transparent mass, and water addition is continued until about one and a half times the weight of the cellulose sulpho-carbonate has been added, when the desired degree of viscosity for working is usually obtained. Like the soda-cellulose before the disulphide is added, viscose is easily decomposed by the action of the air, and specially when the temperature is high; so that it can only be kept in store for use in a cooled chamber where the temperature is below 45° F.; and it is usual to place it in vessels and then to pour slowly on the top of it a layer of water which, unless the mass is agitated, will not combine with it, and the lid of the

vessel is arranged so as to form a water seal so that all air is excluded. If these precautions are not followed a thin layer of cellulose arising from the decomposition of the viscose forms on the surface. When the viscose kept at this temperature is removed into the ordinary temperature of the workroom it can easily be manipulated, as it becomes more plastic.

Cross found that in the manufacture of viscose a large saving in the amount of alkali required for making the soda-cellulose might be effected by previously heating the cellulose for some time at a high temperature with dilute sulphuric or hydrochloric acid, thereby effecting, to a certain extent, a preliminary hydrolysis of the cellulose. This may be accomplished by placing the cellulose mass in a digester with a 1 per cent solution of sulphuric or a $\frac{1}{2}$ per cent of hydrochloric acid, and then raising the mass to a temperature of about 280° F. The quantity of acid solution used should amount to five times the weight of the cellulose. The treated cellulose is then thoroughly washed to remove the acid and then air-dried. By this preliminary treatment the proportion of the mercerising soda ley required for the conversion of the cellulose into soda-cellulose can be taken as follows:—

Cellulose	40 to 50 per cent.
Caustic Soda . . .	10 to 12 per cent.
Water, including that contained in the cellulose .	40 to 50 per cent.

Without this preliminary treatment the same quantity of soda ley would be required to treat only 25 per cent of the cellulose, instead of 40 to 50 per cent.

Uses of Viscose.—Viscose is now being employed in the preparation of cellulose filaments in place of the

nitro-cellulose compounds, and is said to give a higher lustre, and does not require denitration, which usually deteriorates the fibre, and causes it to lose a part of its lustre; but its principal use is in the manufacture of varnishes and sizes for paper and other fabrics, and for the manufacture of the solid viscoid.

The fact that viscose, when exposed to the action of air, undergoes slow decomposition, and when the volatile products are driven off leaves a smooth layer of insoluble cellulose that is insoluble in water, renders it a fit medium for many technical purposes.

Flock Papers.—It is used as a thickening agent in the printing of wall-papers, and now forms the medium used by papermakers as the base upon which to deposit the wool dust used in making flock paper. If used as the medium for printing metallic surfaces by mixing along with it powder of aluminium, bronze, and other bodies, the substance so treated has a beautiful metallic surface and sheen, which has exactly the appearance of a portion of the metals, and when thoroughly dry adheres so firmly that it becomes perfectly fixed and cannot be rubbed off. Surfaces can in this way be prepared of any colour, by mixing the viscose with suitable pigments and fillings, which make it have any surface from that of ivory to any required shade, and which is perfectly flexible and insoluble in water or weak alkalies, so that it can be washed without injury.

In mixing powdered pigments or metallic dust with viscose it is necessary to place the water required to give it the necessary strength in a hollander, and then pour in the viscose and mix the solid materials in afterwards, until the complete mixing is attained. By the use of viscose also almost exact imitation of leather may be obtained.

The fabrics which form the basis for the artificial leather must be thoroughly dried before impregnation with the viscose, and care must be taken that the solution of viscose is of the necessary density to give body to the fabric. This operation must be performed in closed vessels, through which the fabric is drawn, and with rollers which are set so as to regulate the amount of viscose required and squeeze out the remainder. These vessels must be connected up to a vacuum-pump, so that the products of decomposition can be passed into condensers, as they contain bisulphide of carbon and other products, which must be recovered for further use. The soda can be dissolved out by water, and the process repeated until the desired thickness is attained. A last coat of thinner solution will leave a perfectly smooth surface. The material so impregnated may be used for embossing and any other purpose, and the surface printed with any material, thickened with viscose, which will adhere to the cellulose surface in the most complete manner.

Artificial leather so obtained is both finer and stronger than natural leather, and can be used for similar purposes, such as shoe soles or driving bands for machinery, by cementing thin layers together by the use of viscose solutions, until the desired thickness is attained.

Building Materials.—Ordinary cardboard, impregnated with alum or soluble glass solution and then treated with viscose and rolled, may be formed into sheets which are almost fireproof, and can be used in building frame-houses; and felt, impregnated with antiseptic solutions and then with viscose, becomes indestructible to ordinary reagents, and forms a most effective waterproof material for roofing.

Artificial Flowers.—Thin gauze materials impregnated with viscose may be obtained of any degree of thickness and colour, and can be used in the manufacture of artificial

flowers, having all the appearance of wax flowers, but are far more durable and indestructible by ordinary atmospheric action; while canvas can be rendered perfectly waterproof and will not rot or decay even after prolonged exposure to damp, so that such material is specially useful for tents.

Thin films prepared from viscose can be obtained, which form a far more desirable material than any which can be got by the use of nitro-cellulose, and are now being used in photography, and are quite as transparent and almost non-inflammable, so that they can very advantageously be employed for cinematographic purposes.

Viscoid.—As already seen, when viscose is allowed to dry and the film so obtained treated with water to wash out the soda, a transparent film of pure amorphous cellulose is obtained. If the solution of viscose is poured into moulds masses of transparent cellulose may be obtained in the form of blocks, which can be worked with tools into any desired shape. In preparing such blocks care has to be taken to cool very slowly, or the gases given off by the decomposition will form bubbles or cavities and so interfere with the transparency.

When the consistency in the mould has attained that of a strong jelly the mass may be taken out and allowed to remain in a place free from dust until the change is complete, and then placed in an oven and slowly heated to a temperature not exceeding 212° F. The block is then soaked in water to remove the soda, and, when this is all taken out, is subjected to a high pressure for some time in a press, when it consolidates into a block which can hardly be distinguished from glass.

If the viscous material, before setting, is mixed with filling material so as to give it a greater solidity or make it resemble ivory, marble, or any other substance, it can, while

retaining a certain amount of viscosity, be pressed into any desired form and used for an infinite variety of purposes, from the manufacture of billiard-balls to door-handles and finger-plates, since it possesses the utmost brilliancy of surface with the greatest toughness and durability.

Action of Alkaline Cupric Salts upon Cellulose.—The action of acid salts, such as the chloride of zinc, upon cellulose, with which they readily form solutions, when heated or in the cold, when hydrochloric acid is added, has already been considered. Alkaline salts, and especially when mixed with metallic oxides and notably oxide of copper, form a solution which readily dissolves cellulose, and has proved, under the name of Schweitzer's reagent, a great aid in the microscopical investigation of the structure of the cellulose walls of the cotton and other vegetable fibres. This remarkable action appears to have been first observed by Mercer when investigating the action of alkalies upon cotton. He employed a solution of ammonia of a sp. gr. 0·920 saturated at the ordinary temperature with cupric oxide (hydrate) diluted with three volumes of water. In investigating the reaction in relation to the influence of different conditions of treatment he found that solutions obtained by decomposing the copper salts with excess of ammonia were much less active than when he used equivalent solutions of the pure hydrate, and that the action was greatly retarded by raising the temperature to 100° F., at which point it became very slight. He applied a solution of cupric nitrate to cotton cloth in spots, and after decomposing the nitrate with a weak solution of caustic soda and removing the excess of alkali by washing, he partially dried the cloth and then plunged it into ammonia gas, when the action was at once apparent. Cross and Bevan point out that this action arises from the presence in

the cellulose molecule of OH groups of opposite function, basic and acid, and that the compounds formed with the solvents are of the nature of double salts.

Preparation of Cuprammonium Solution.—There are several methods of accomplishing this; the simplest is to a solution of cupric salt ammonium chloride is added, and then sodium hydrate (caustic soda) in sufficient excess, and the blue precipitate obtained is then thoroughly washed and all the excess of moisture removed by squeezing. The precipitate is then dissolved in a solution of ammonia of 0·920 sp. gr. The solution should now contain 10 to 15 per cent of copper oxide, CuO. On the large scale for use in the preparation of cellulose solutions for commercial purposes, the solution is prepared by treating copper turnings with ammonia in the presence of lactic acid, at a temperature as near as possible to 40° F. It requires about ten days before the cuprammonium solution is completely prepared.

The action of this solution is very slow upon pure cellulose, but very active when in the form of cellulose hydrate, and hence for cellulose solutions mercerised cotton is always used. For making the cellulose colloid required in manufacturing artificial silk the following process is usually followed.

The cellulose hydrate is obtained by mixing 100 parts of cellulose with 1000 parts of a solution containing 30 parts of sodium carbonate and 50 parts of caustic soda. This mixture is then heated in a digester 3½ hours at a pressure of 40 lbs. per square inch. The mercerised cotton, bleached with chloride of lime, is again washed and dried and then dissolved in the cuprammonium solution. The solution, which contains from 7 to 8 per cent of the cellulose, is then settled and filtered under pressure, and is

then ready for use in spinning. The most important process, when the colloid is to be used for spinning, is the filtering process, because if the least particle of mechanical impurity is present it will fill up the spinning nozzles and entirely prevent the obtaining of perfect threads. It pays, therefore, to use nothing but the purest raw material, and to secure that the mercerising of the cotton is complete, so that all will be equally and perfectly soluble in the solution.

It is almost unnecessary to add that in using the cuprammonium process nothing but copper-lined vessels must be used, and they should also be air-tight, when the process is in operation, so as to prevent the evaporation of the ammonia from the solution which causes it to decompose, and also all air must be excluded so as to prevent oxidation. When the threads pass out of the spinning nozzles they are passed through a bath containing 30 to 65 per cent of sulphuric acid, which coagulates and hardens them. This method of treatment produces threads which require no denitration; and the lustre of the fibres, which is very high, is therefore unimpaired, and on this account many technologists are now of opinion that this process and the use of viscose in place of nitro-cellulose derivatives will supersede all others.

This property of cuprammonium salts to dissolve and gelatinise cellulose has been employed in surface-treating thick cotton cloth, to compact the component fibres together and give a waterproof glaze to the fabric. Cloth so treated retains the copper oxide on the surface, and when it dries it colours it a bright malachite green, which in addition to being waterproof acts as a preservative against the attacks of insects and vegetable growths such as mildew.

It is now being largely used for cart, waggon, and rick and tent covers.

Action of Alkaline Zinc and Lead Salts.—The copper in cuprammonium can be replaced by zinc and lead oxide forming zinc ammonium hydroxide, which gives a colourless solution of cellulose, and precipitating, when the cuprammonium solution is treated with finely divided lead oxide, a compound of cellulose with lead having the composition $x(C_6H_{10}O_5 . PbO)$.

CHAPTER IX

CHEMISTRY OF THE COTTON FIBRE—*continued*

Mercerising Process.—Although the mercerising of cotton has been incidentally mentioned in relation to the treatment of cotton or cellulose as preparation for solution in various reagents, still, the process, in the application of it to industrial use is so important that it merits special consideration.

In 1850 John Mercer, a Lancashire chemist, discovered that if cotton fibres were soaked in a cold solution of caustic soda of a sp. gr. of 1·3 or 1·4 they became stronger and fuller, converting thin and coarse cloth into strong and fine cloth, with improved powers of receiving colour and making the colours more permanent. These three important and very remarkable alterations occur at the same time—the fibre becomes stronger, it acquires increased attraction for colouring matter, and it also becomes finer. It frequently happens that chemical reagents have a weakening action upon the fibres subjected to them, but in this case it is the reverse.

A valuable paper dealing with this subject was published in the *Chemical Journal* of 1863 by Walter Crum, F.R.S., who pointed out that if the unripe and perfectly collapsed fibre is subjected to the mercerising process, it at

once assumes the round solid form of ripe cotton, differing from the naturally matured and ripened fibres only in being smaller, more generally cylindrical, and having a larger aperture or lumen in the centre. He adds: "It may now appear not improbable, that by the process of ripening an effect is produced similar in character to that which is given to the unripe fibre by artificial means, and that the natural expansion may be ascribed, not to the importation of a new kind of matter coating the interior of the original cell-wall, but to a strengthening and rendering elastic of the membrane, already existing, of the wall itself, so as to produce the separation from each other of the cells, or concentric laminæ, or other structure of which it must consist."

If this be the case, the tube walls of a fully matured and ripe cotton fibre really consist of a series of tissues of pure cellulose, which are separated from each other by a series of intervals of more or less dense cellular tissue, forming a series of capillary surfaces, which act with the utmost energy upon any liquid in which the fibres may be immersed, and which will fully account for the extraordinary absorbent power which the cotton fibres possess. Crum believed that the thin pellucid outer sheath of cellulose acts as a dialyser, and under the laws of osmotic action the surrounding liquid passes into the inner cells, whose thin transparent walls act in like manner; and by a series of these actions the liquid is gradually passed inwards, until it finally reaches the inner cavity or lumen. Upon these observations he formed the opinion that the dyeing of cotton was almost a purely mechanical action which, however, is now generally discarded.

This dialysing process will of course take place to the

greatest degree when the formation of the cotton fibre is most perfect, and when, as in the fully ripe and mature fibre, all the cell-contents have been changed into pure cellular tissue, leaving the free cellular spaces between the laminæ perfectly unfilled; and therefore, like so many capillary tubes, able to exert the utmost force of which they are capable in drawing inwards and retaining any liquids which may be presented to them. The action of the alkali which removes the oil and wax which are always found on the surface of the fibres also prepares the surface, which was so protected, so that it becomes more absorbent and thus more attractive to any colouring matter present in any solution presented to it.

In 1883 the author of this book, while experimenting on the mercerising of yarn with a view to ascertaining the best strength of the caustic soda solution to impart the maximum strength to yarn so treated, used the swift of an ordinary warp reel on which the yarn was wound, to immerse the cotton hank into the caustic solution, and was astonished to find, when the yarn was washed in the same manner, that the lustre of the yarn was very greatly increased, and in the case of Egyptian cotton especially, the lustre was almost equal to silk. He exhibited hanks of this yarn at a lecture he delivered at the Bradford Technical College in connection either with the Society of Chemical Industry or the Society of Dyers and Colourists, and strongly advised the chemists who were present to further investigate this matter, as likely to lead to important industrial results. This process of lustering yarn is now largely used; but the author believes that he was the first to point out the special adaptation of Egyptian cotton for this purpose. In the mercerising of cotton there are two distinct changes which take place, and

which are coincident with the two phases which the cotton undergoes, the one of which is chemical and the other mechanical. The first is the chemical action of the alkaline solution, which effects a chemical transformation in the molecular structure of the fibre, by the formation of a chemical compound with the caustic soda and the cellulose in the molecular ratio of $C_{12}H_{20}O_{10} : 2NaOH$, accompanied by combination with water (hydration), and a further change when the cotton is washed in water so as to remove excess of alkali. During the process of washing this compound of cellulose and alkali is decomposed, the alkali being recovered unchanged in solution in the water, and the cellulose reappearing in the form of cellulose hydrate, $C_{12}H_{20}O_{10} . H_2O$. If the alkalinated cotton is treated with alcohol, in place of water, only one-half of the alkali is recovered in the solution, and the cellulose is associated in the ratio $C_{12}H_{20}O_{10} : NaOH$, which is known as alkali-cellulose. The cellulose hydrate is the basis of mercerisation.

The second change is mechanical, and the result of washing the mercerised cotton under tension that is necessary to prevent too great shrinking of the cloth or yarn, and which, while the general physical appearance of the fibres remains the same, results in the swelling of the fibres with all the characteristics of greater ripeness and an increase in strength and surface lustre. This physical change is very remarkable, and fully accounts for the increased lustre which is observed in mercerised yarn.

One of the technical difficulties connected with the mercerising of yarn was, until recently, that of ascertaining whether all the yarn was properly mercerised, as, unless the yarn is thoroughly cleansed and the caustic solution of the right temperature and strength, irregularity is sure to

be manifested when the yarn comes to be dyed afterwards. Also when these defects were patent, it was often difficult to decide who was at fault in the matter—the merceriser, dyer, or finisher. Quite recently, however, Mr. Julius Hubner, M.Sc.Tech., F.I.C., of the Manchester Technical College, read a paper entitled "New Reactions for the Characterisation of Mercerised Cotton," before the Manchester Literary and Philosophical Society. The author stated that hitherto no reliable chemical reaction for the characterisation of mercerised cotton was known. He had found, however, that on immersing mercerised and ordinary cotton in a solution of iodine in saturated potassium iodide solution for a few seconds, and afterwards washing with water, the colour of the mercerised cotton quickly changed to a bluish-black, whilst the ordinary cotton became lighter in colour, and changed to a brownish-chocolate shade. After further washing the ordinary cotton became white, whilst the mercerised material remained a bluish-black colour, which faded very slowly on prolonged washing. The reaction proceeded still more distinctly and more slowly if, in place of water, a two per cent solution of potassium iodide in water were used for washing the cotton after immersion in the reagent. It would then be noticed that after five or six washings the mercerised cotton was of a brownish-black shade, whilst the ordinary cotton appeared practically white. If now water were added the colour of the mercerised cotton changed immediately into a bluish-black, whilst the ordinary cotton remained white. On applying the reagent described above to cotton mercerised with caustic soda of different strengths, it had been found that a distinct gradation of colour was produced, which was directly comparable with Hübner and Pope's results as to colour absorption, shrinkage, and other mechanical

properties of cotton similarly treated. On drying the blue-coloured cotton, after washing, the colour was found to fade gradually. If the cotton were dried without washing the brown colour of the ordinary and of the weakly mercerised cottons faded rapidly, whilst the more strongly mercerised cottons retained the iodine for a very long time, in some cases even for six weeks. The author has further found that, if ordinary mercerised cotton were immersed in aqueous solutions of zinc chloride to which two drops of a solution of iodine in potassium iodide had been added, the minute quantity of iodine present exhibited quite a remarkable action on the cotton fibres. The strength of coloration of the cotton increased to a certain point with the increase in the strength of the zinc chloride solution the shade of the colour altered, and the difference in the strength of coloration between the mercerised and the ordinary cotton increased also with the strength of the zinc chloride solution until 100 cc. of solution contained 93·3 grains of zinc chloride, when the ordinary cotton remained practically white, whilst the mercerised cotton appeared a dark navy blue. Cottons which had been mercerised with different strengths of caustic soda solution showed with this reagent also a gradation in colour by means of which the degree of mercerisation of a given sample might be ascertained. It was pointed out that these reagents might prove of value in the distinction of other textile and papermaking fibres, the various artificial silks, etc.

Microscopical Appearance of Mercerised Yarn.—When the fibres are examined under the microscope in the ordinary untreated condition they present, as has already been seen, the appearance of a number of more or less irregularly twisted ribbons, or a series of tubes which

have collapsed and been twisted on their longitudinal axis, sometimes in one direction and then in another in the most irregular manner. They also exhibit, especially in the case of fibres which are not fully ripe, a surface filled with wrinkles and irregular folds caused by the shrinking in of the interior layers of which the cell-walls are composed, and the consequent shrivelling of the outer layer or pellicle. When the cotton is

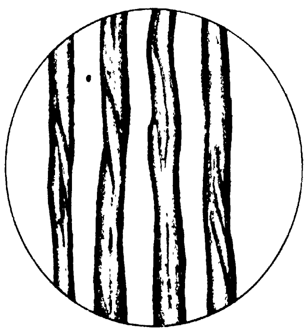

FIG. 47.—Fibres of Egyptian Cotton Mercerised. × 200 diameters.

mercerised this appearance is entirely changed, and the fibres swell up, and in swelling the reverse process of drying up is exhibited. The inner layers are fed by the alkaline solution and hydration, and their thickness is restored and most of the twist taken out of the fibres; and as the twist was not, like the threads of a screw, formed by rotating the substance of the fibre on its longitudinal axis a given number of times, but by the leverage action of the outer surface of the tube upon the more solid structure of the innermost layer surrounding the central

cavity of the tube, the twists gradually uncoil, and the taking out of the twist in one direction is balanced by the taking out of that in the other direction, and most of the fibres are seen as more or less solid tubes with a surface possessing a smooth appearance, as all the wrinkles have been stretched out. This action occurs to a certain extent even when the fibres are not under tension, but of course this is greatly facilitated by being kept tight longitudinally.

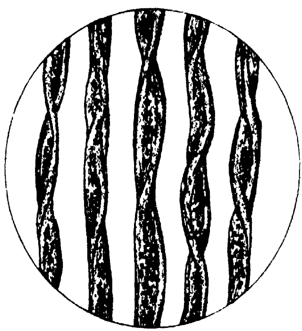

FIG. 48.—Fibres of Egyptian Cotton (Brown) Unmercerised. × 200 diameters.

Fig. 47 gives an illustration of a number of mercerised fibres as seen under the microscope, and these may be compared with unmercerised fibres of the same class of Egyptian cotton given in Fig. 48.

Cause of Lustre in Mercerised Cotton.—The brightness and lustre of the mercerised cotton is due to two causes. The first, that the unwrinkled surface now reflects the light to the eye in regular sheets in one direction similar to that observed on the surface of still

water, which gives perfect reflections of any object; whereas when disturbed even by small waves which correspond to the wrinkles on the surface of the cotton, the surface of the water becomes dull and unreflective as the rays of light are scattered in every direction. The second cause is that the action of the alkali makes a more or less gelatinous and translucent surface to the fibre, which reduces the absorption of the light and increases the reflection.

To obtain the best lustre the author found that it was best, in the case of yarn, to treat the hanks with the alkali in the ordinary way, as if dyeing them without tension, and then apply the tension during the process of washing to remove the alkali. After the lustre is obtained on the yarn and the alkali removed, if the same yarn is again treated with alkali a large portion of the lustre is destroyed, and can never be restored again. This probably arises from the alkali attacking to some extent the surface pellicle of the fibres; and this action is probably considerably increased by the fact that the first treatment with alkali removed the protective covering of wax and oil, and so left the surface more open to disintegration.

Treating the fibre with caustic potash in place of caustic soda gives a more energetic reaction, and the shrinkage is less in length as measured by the force exerted, but the lustre is also less, as might be expected.

Matthews, in the second edition of his work on *Textile Fibres*, page 242, gives an interesting summary of the results of some experiments made by Herbig, which are as follows:—

1. Loose yarn, mercerised without any stretching, whether long or short stapled, and whether with or without a hard twist, has less lustre than unmercerised

yarn, but even with slight tension the lustre becomes greater.

2. Both with long and short stapled cotton, the lustre only becomes marked when the stretching force is sufficient to bring back the yarn to its original length.

3. Stretching beyond the original length does not give any increased lustre.

4. Considerable difference is observable in the stretching force needed between loose mercerisation, followed by stretching, in the ley, and keeping the cotton at its original length during mercerisation, as in the latter case only one-third to one-fourth of the force is necessary to produce the silky lustre.

5. The stretching of the yarn requires only a small force when mercerised loose, and if applied when rinsing is in actual progress, for the best time for stretching is during the conversion of the soda-cellulose into hydro-cellulose.

6. When rinsing is over, twice as much force is needed to restore the original length as is required to restore it when still in contact with the ley, and yarns so treated contract somewhat on drying and exhibit inferior lustre.

7. The stretching force necessary in mercerising yarn varies with the twist, and in general is greater in proportion as the twist is harder.

8. The production of the silky lustre does not depend primarily on the amount of force employed in stretching, as soft yarn, with only a small amount of twist, can be lustered.

9. The production of the silky lustre is independent of the cotton being long or short stapled, as short-stapled American cotton, even with a loose twist, can be given a silky lustre.

10. The production of a high degree of lustre depends

to a considerable extent on the fineness of the fibre and its natural lustre. This is apparent in mercerising Sea Island and Egyptian cotton.

Increase in Strength of Yarn.—An important point in regard to mercerising is that the strength of the yarn and cloth is not in any way impaired, but on the contrary is considerably increased, in some cases to the extent of from 30 to 50 per cent. No experiments seem to have been made in regard to the increase in strength in individual fibres, but there can be no doubt that they are strengthened, because if fibres are mercerised they shrink in length and increase in diameter to the extent of from 20 to 30 per cent, and therefore present a greater and fuller cross sectional area. The difficulty of treating individual fibres under tension would not repay the trouble of investigation, but it is quite different when they are mercerised when associated in the thread, as this is the form in which they are used commercially.

Grosheintz (quoted by Matthews) gives the following result arrived at by some experiments conducted by himself, but does not give the counts of the yarn :—

TABLE OF RELATIVE STRENGTHS OF MERCERISED AND UNMERCERISED YARNS

Unmercerised Yarn.	Mercerised in Cold Caustic Soda.	Mercerised in Cold Alcoholic Caustic Soda.	Mercerised in Hot Alcoholic Caustic Soda.
Strength in grammes.	Strength in grammes.	Strength in grammes.	Strength in grammes.
350 to 360	530 to 570	600 to 645	690 to 740

He does not give either the counts of the yarn or the quality of the cotton or the length which was tested at the same time. Neither does he give the twist in the

yarn. From these experiments it seems that the yarn mercerised in the ordinary way increased in strength about 60 per cent, and upwards of 100 per cent by the use of alcoholic solution of soda in place of the usual water solution.

To determine this point a number of experiments were made by the author some time ago, the quantity tested at a time being a lea from an ordinary cotton hank, and the tests were made on a yarn tester driven by power, which will be described later on. The yarn was mercerised in a cold solution of caustic soda sp. gr. 1·35 without tension, but rinsed under tension, and after drying left in the testing-room at a temperature of 62° F., under ordinary atmospheric conditions.

The strengths of yarn given in both the mercerised and unmercerised yarn are the average of five leas each. This applies both to the single and twofold yarns. The following are the results obtained:—

TABLE OF STRENGTHS OF MERCERISED AND UNMERCERISED YARNS

SINGLE YARNS

Nature of Cotton used.	Average Counts Standard.	After Mercerising, lbs. per lea.	Before Mercerising, lbs. per lea.	Gain in lbs. per lea.	Gain per cent.
American cotton	20s mule	103	78	25	32·5
Egyptian and American . .	20s mule	138	102	36	34·5
American cotton	20s water	107	81	26	32·1
,,	32s mule	64	52	12	27·2
Egyptian cotton	40s mule	73	54	19	35·2
,,	50s mule	46	35	11	31·1
,,	60s mule	42	32	10	31·3
,, Super combed	60s mule	46	34	12	35·3

It will be seen from this table that the average increase in strength in the American yarns is 31·6 per cent, while that of the yarns made from Egyptian cotton, exclusive of the combed yarn, is 33 per cent, and that of the combed yarns above 35 per cent.

It is interesting to compare this increase in strength in the single yarns with a number of tests made with twofold yarns with standard twist, and they were mercerised and tested under the same conditions as the single yarns.

TABLE OF STRENGTHS OF MERCERISED AND UNMERCERISED YARNS

TWOFOLD YARNS

Nature of Yarn used.	Average Counts, Standard twist.	After Mercerising, lbs. per lea.	Before Mercerising, lbs. per lea.	Gain in lbs. per lea.	Gain per cent.
American cotton	2/40s twiner	154	104	50	48·0
Egyptian cotton	,,	162	108	54	50·0
,,	2/40s frame	166	110	56	51·0
,,	2/38s ,,	193	130	63	48·0
,,	2/60s ,,	122	82	40	48·7
,,	2/60s twiner	127	85	42	49·0
,,	2/80s frame	92	62	30	48·0
,,	2/120s ,,	76	52	21	46·0
Sea Island cotton	,, ,,	94	60	34	52·8

While the single yarns made from American cotton increase only 31·6 per cent, the twofold yarns made from the same cotton increased 48 per cent. The Egyptian single yarns increased 33 per cent, but the twofold Egyptian yarns nearly 43 per cent, and the Sea Island super combed twofold yarn 52·8 per cent. From these experiments it appears that the yarns tested by Grosheintz must have been twofold, and probably extra twisted, or else that they

were mercerised without tension, since some experiments made by Buntrock showed that if cotton was mercerised without tension, and therefore allowed to shrink freely, the strength was increased 68 per cent; while under tension it only increased 35 per cent, which, if they were single yarns, closely corresponds to the 33 per cent, and in the case of the combed single yarn 35 per cent in the above tables.

So far as the action of the mercerising process upon the fibre is concerned it is the same both in the single and twofold yarns, and the individual fibres are probably strengthened equally. The difference in strength between the two, therefore, lies in the way in which the fibres are held bound in the thread, and this difference is even more striking in the difference before mercerising between the single and double yarns of the same counts. Twenties single, mule spun, which corresponds to forties twofold, have a strength of only about 75 lbs. per lea as against 100 in the twofold yarn. In the single yarn the fibres can only be twisted to the extent of their individual length, and the catch or hold which they have upon each other is limited to their individual surface and the length of the staple, and they therefore, when subject to strain, lose their hold upon each other, and draw out; and when the broken end of a single yarn, if unsized (which cements together) is examined it is very seldom any of the fibres are fractured, as they are simply drawn out. Hence single yarns cannot be made to stand the tension in rinsing which is necessary to attain a high lustre. Twofold yarns have a much firmer grip, because in addition to the hold of the individual fibres upon each other in the single yarn there is the associated grip of the two cylindrical threads wrapped round each other, and enabling a much higher tension to be

resisted. As a consequence, when the broken end of a twofold yarn is examined, many fibres are found to be fractured. It is usual to put less twist into single yarn used for doubling than when used for warps and sizing, and this enables the two twisted threads, as being softer, to bed more closely into each other and so resist tension, besides giving the yarn a softer feeling with the same twist in the doubling. When single yarn is mercerised in the cloth it may be made to receive a higher lustre, because the cloth will stand the necessary tension to prevent shrinking, as the threads are now interlaced, and therefore give mutual support to prevent drawing out, and in this way act as if the yarn was twofold.

Increase in Elasticity.—As might naturally be expected, mercerised yarn, when prepared without tension, shows an increased elasticity, because the fibres have been allowed to shrink up as much as they can; when, therefore, they are subjected to tension the elasticity is about 17 per cent as against about 11 per cent in the same yarn before mercerisation, an increased elasticity of 55 per cent. When the yarn has been rinsed under tension a certain quantity of the elasticity has been taken out of the yarn which cannot be regained when the yarn is dried.

Time of Mercerising.—The action of the cold alkaline ley upon the fibre in forming the soda-cellulose is very rapid, and is completed in a few minutes, not more than ten minutes being necessary, and the time appears to be quite independent either of the exact strength of the solution or of the temperature. The yarn or cloth ought to be removed as soon as ever the process is complete, because continued contact with the ley is not only unnecessary but also injurious, as the alkali attacks the surface of the fibre and reduces its lustre, if kept immersed too long. This

probably arises from the fact that when the cotton wax and oil is removed from the surface of the outer pellicle it is no longer protected from its action, and being attacked, suffers both in lustre and strength. This deleterious action is greatly accelerated if the temperature is too high, and is probably increased by the tendency, if exposed to the action of the air, to form oxycellulose by hydrolysis and oxidation.

Improvements in Mercerising.—Since Mercer's time many attempts have been made to improve the process and increase the beneficial effects on the cotton, in some cases, by the use of other chemicals than soda ash to bring about the hydration, but mostly by addition of others to the soda-ley or by some preliminary treatment to assist or modify it action. Strong mineral acids and metallic salts, such as chlorides of calcium, zinc, and tin, have been employed, but they do not give any results equal to the sodium salt, and all more or less tender the yarn and give inferior lustre.

The addition of alcohol along with the soda-ley is said to increase the strength, as appears in Grosheintz's experiments, and the addition of glycerol, or previous treatment with turkey-red oil, which seems to assist in the more complete penetration of the soda-ley; but whether this results from any chemical change or only from the action of these substances in a more complete manner by removal of the waxes, oils, and other cell-contents, which if unremoved hinder the absorption, does not appear clear from any experiments which have been made.

When bleach white is required with mercerised cotton it is a matter upon which opinions seem to differ, as to whether the bleaching should be done previous or subsequent to the mercerising, but the latter seems to be

the practice generally employed. The rationale of this is not far to seek, because the bleaching action opens the pores of the outer pellicle of the fibre, and specially in the presence of calcium hypochlorite, $Ca(OCl)_2$, which is always more or less present in bleaching powder, and this renders the fibre substance more likely to be injured by the strong caustic solution. There is also a chemical action which occurs with the cellulose, which renders the surface of the fibre less able to enter into chemical union with the soda, so as to effect the mercerising process, in the best possible manner. In mercerising cloth which contains sizing materials, even after due precaution has been taken to remove them, it is necessary carefully to watch that the temperature of the soda-ley does not rise, otherwise the process will not be effectually carried out; also when cloth or yarn is to be bleached after mercerising it is not necessary to entirely remove the whole of the soda-ley either by rinsing during the stretching process or by neutralising with weak acid, as a small quantity of alkali assists rather than retards the bleaching process, but special care must be given to see that the strength of the bleaching powder is not too great, or the temperature too high, or the time too prolonged, otherwise the lustre will be impaired.

Action of Chlorine on Cellulose.—Dry chlorine gas has no action upon cellulose, but in the presence of moisture there is a reaction which is specially active in destroying colouring matter; and in the form of various chlorine compounds such as the hypochlorite and chlorides of the earths and metals we have already seen that it acts in the same manner as one of the mineral acids. Also that in the carbonising process for the destruction of vegetable (cellulose) fibres the hydrolising agents in the form of

chlorine salts depend for their action upon the liberation of chlorine in the presence of heat and moist cellulose, and the formation of oxychlorides.

Singeing.—Before bleaching goods it is essential that all short fibres or fluff on the surface of the goods be removed, otherwise the cloth will have a matted uneven appearance when finished. The cloth is therefore, as a preparation for bleaching, passed over a series of bunsen gas jets at a sufficient speed to prevent burning the cloth but singeing off all the hairs. Care must be exercised to prevent the cloth being scorched or the temperature becoming too high, otherwise it may decompose the magnesium chloride used in the size, and the cloth be thus tendered by the after process in the bleaching by the conversion of the hydro cellulose so produced into cellulose.

Bleaching.—No industrial operation in the manufacture of cotton is of more importance than the bleaching process, because it not only removes any colouring matter which may be present, as endochrome in the fibre, but also frees it from other oleaginous and other organic impurities which, unless removed, would seriously interfere with the dyeing process, and specially when light colours are to be used.

In the bleaching process itself it is not, however, the chlorine which is the active agent, but the nascent oxygen, which is liberated by the action of the chlorine upon the moisture in which the water is decomposed, according to the formula as follows—

$$Cl_2 + H_2O = 2HCl + O.$$

The hypochlorites act in the same way by the decomposition of the liberated hypochlorous acid into hydrochloric acid and oxygen, according to the formula—

$$HClO = HCl + O.$$

The same action holds good from whatever source the chlorine is derived, whether by liberation from bleaching powder or its direct production in the bleaching liquid by any of the methods of electrolysis which are now in use.

Although there are other bleaching agents which might be employed, still the one most generally in use is bleaching powder made by the absorbent action of lime upon chlorine gas. The exact composition of bleaching powder is uncertain and variable.

When calcium hydroxide, $Ca(OH)_2$ is acted on by chlorine it appears as if the obvious action would be as follows:—

$$Ca(OH)_2 \text{ with } Cl_2 = CaCl(OCl) + H_2O.$$

According to this reaction the bleaching powder would result from the substitution of Cl for one of the OH groups, and the removal of the H of the other as H_2O, this atom of H being exchanged for Cl; but this reaction would necessitate the calcium hydroxide absorbing nearly an equal weight of chlorine, whereas there is never more than half this quantity present in the bleaching powder. It is difficult to ascertain the exact quantity, except as an average, because so much of the lime is entirely unacted on. In the solid state, when in perfect condition, the composition may be represented roughly as $Ca\begin{matrix}\diagup OCl \\ \diagdown Cl\end{matrix}$, but when dissolved in water it has the normal composition of a hypochlorite which corresponds with the formula $Ca(ClO)_2$.

Preparation of Bleaching Powder Solution.—The

solution must be made in the cold, and great care exercised that there is no rise in the temperature, or decomposition sets in rapidly. The powder, as taken from the casks, must be broken up so as to contain no large or hard lumps, and the solution, which is usually prepared in stone troughs or cisterns, must be allowed to stand to deposit any undissolved particles, because if these are deposited on the yarn or cloth, they will not only destroy the colouring matter but attack the fibre also, and convert some of the cellulose into oxy-cellulose, which will cause defects in the dyeing by reaction with the dye stuff. The strength of the solution employed is usually varied to suit the purpose for which it is intended, but seldom exceeds $2\frac{1}{2}°$ B.

Preparation of Cloth for Bleaching.—The goods are first wet out with hot water and then plaited and laid out in a pile and allowed to stand twelve or fourteen hours. This produces decomposition in the size and renders it removable in the washing process before liming. This washing must be thorough, so as to keep the lime kiers clean and prevent kier stains. The kiers must be lime-washed in every part every few weeks to prevent any possible contact of the goods or yarn with the iron of the kier, and so avoid iron stains. Some firms use the kiers alternately for liming and alkalinating, and thus keep them in the best possible condition.

Process of Bleaching.—In the bleaching process there are usually five stages:—

1. The yarn or goods are steeped and then boiled in lime water, which dissolves out or changes the unchanged organic substances such as pectoses into compounds which can readily yield to the after treatment. The lime water is prepared by mixing $\frac{1}{2}$ cwt. of quicklime with 100 gallons of water, and passing the mixture through a sieve.

The yarn or cloth is then transferred to the bowking kier, which is a large enclosed iron boiler, having a false bottom which is drilled with holes. A pipe fixed into this false bottom rises vertically from the centre, and reaches about three-quarters up the centre of the kier. A cowl to deflect the water downward over the goods is placed on the top of the pipe. Cloths are placed on the false bottom and the kier then filled with the limed goods packed close, until they reach nearly the same height as the stand pipe. The goods are then covered over with cloths and the water run into the kier until it covers the goods. The lid is then fastened down and high-pressure steam turned into the bottom of the kier until the water boils. In consequence of the weight of goods on the false bottom, which offers a greater resistance to the upward passage of the water than does the open pipe which passes up from beneath the false bottom to the level of the goods in the upper division, the boiling water is projected up through the central tube and, spouting over the goods, passes down through them into the space below the false bottom, and so the boiling liquor is kept under pressure, in constant circulation, for several hours, according to the character of the charge. The kier is fitted with a loaded safety-valve, as the pressure must be from 40 to 50 pounds per square inch.

It is essential in all kier processes that the liquor entirely covers the goods, so as to prevent any possible contact with the oxygen of the air, which, either in the liming or alkalinating process, would cause faults or tendering in the goods.

2. When the liming is complete the goods are thoroughly washed, and special care must be taken to prevent the lime drying on the goods, otherwise it will be almost impossible to remove it, and the goods will be damaged.

They are then treated with a solution of hydrochloric acid 2° B. strength, and left covered up in a wooden vat for about half an hour, and then thoroughly washed with water. The use of sulphuric in place of hydrochloric acid is very objectionable, as the sulphate of lime is insoluble, and will fix on the goods, and defy removal by washing.

3. A solution is now prepared by boiling 10 lbs. of rosin soap with about 35 lbs. of soda *alkali* in twenty gallons of water for about six hours. This is diluted with eight times its own volume of water, and this solution, along with the goods, is placed in a similar kier to that used in the first process, and boiled for about twelve hours under a pressure of from 40 to 50 lbs. as before. It is essential for good bleaching that this process must be carefully attended to, as it prepares the fibres for the after treatment with the chlorine by removing the last traces of oily matter and cell-contents. The goods are then thoroughly washed with boiling water to remove all the rosin and soda.

4. When this washing is completed the goods are steeped in a freshly made solution of the bleaching powder of a strength of $\frac{3}{4}$° B., and left alone in a dark place for about an hour, or steeped for about six hours in a weaker solution of the bleaching powder, about $\frac{1}{3}$rd B., and then thoroughly washed in water to remove the reagent. It is essential that the bleaching solution entirely covers the goods.

5. The washed yarns or goods are then treated again with a dilute solution of hydrochloric acid 1° B. strength, and left exposed to the air for half an hour or steeped for several hours in a more dilute solution of the acid, so as to remove the last traces of the chlorine, which would

otherwise weaken the fibre of the cotton, and are then again thoroughly washed and may then be dried.

Strength of Yarn after Bleaching.—When the operation of bleaching is properly conducted, with the alkali, bleaching liquor, and acid of the best strength, and the goods properly washed, no weakening will take place; on the contrary, they are rather strengthened, and the cause is probably the same as in the mercerising process—that hydrolysis has taken place the same as in mercerising, and the shrinkage of length has been compensated for by a feeding and thickening of the fibre.

O'Neil determined the strength of both warp and weft before and after bleaching, and gives the following as the result:—

STRENGTH OF BLEACHED AND UNBLEACHED YARN

Class of Yarn.	Average Weight to break a Single Thread.	
	Before Bleaching.	After Bleaching.
No. 1 Cloth weft	1714 grains	2785 grains
No. 2 Cloth warp	3140 ,,	2020 ,,
No. 3 Cloth warp	3407 ,,	3708 ,,
No. 4 Cloth warp	3512 ,,	4025 ,,

The weft is increased in strength 62 per cent, and the warp on the average 9 per cent. The astonishing result is the great difference between the increase in strength of the warp and weft. He does not give the counts.

CHAPTER X

CHEMISTRY OF THE COTTON FIBRE *continued*

Wax, Oils, and Fat.—The fibres of every class of cotton have associated with them, either as a protective agent, on the surface, or between the layers of which the cell-wall is composed, a certain amount of oily matter, which dries up into a wax, and also a large amount of oil is always contained in the seed, the extraction of which has become a large industry.

The quantity of the oil contained in the seeds and the fibre varies with the seasons and with the degree of ripeness of the boll. Large quantities of cotton-seed oil are expressed from the seeds after the process of ginning is complete, and the presence of this oil, to a more or less extent, in the cells and on the surface of the fibre, is the cause why an elevated temperature is essential, especially in fine spinning, in the rooms where the spinning of the cotton is carried on.

As the temperature falls, the oily wax tends to become stiff and gummy, and prevents the proper drawing out of the fibre during the spinning process, while its presence between the thin walls of the lamina forming the tube of the fibre, tends to give greater elasticity to the fibre and render it less liable to sudden rupture.

The gradual drying up of the more volatile portions of this oil in the fibre, leaving the remaining portion thicker and stiffer, may also and probably does account for the fact that is quite well known to spinners, that new crop cotton works better and makes less waste than as the season advances, and which the author has often heard expressed in the words:—New crop cotton has "more nature" in it than the old crop.

Upon the presence, also, of this oily wax depends the "setting" process, which all cotton yarns require after they are spun, in order to increase the strength and take away the curl produced by the twist in the thread, a process which, in the case of single yarns, is called "conditioning," and is usually accomplished by keeping them for some time in a cold and moist place, where the natural oil and wax becomes stiff and dry after the high temperature to which it has been subjected in the spinning rooms.

In the case of yarns for doubling purposes this is accomplished by subjecting them to a high temperature in a close box under steam pressure before being doubled into the twofold yarn. This process of steaming darkens the colour of the yarn, and specially where Egyptian cotton is used; and to retain the light colour it has been found that by dipping the yarn, in the crop, into a cistern of cold water, by the process of submerging the skips for about a minute, and then allowing the surplus water to drain out, the colour is not darkened, and the yarn, when dried slowly for a few days, becomes completely "conditioned," and can be used for doubling, as the curl is entirely removed. The length of time required to condition yarn varies with the counts and the amount of the twist, but it must be sufficiently long to enable the fibres of cotton, which have been subjected to torsion in the spinning process, to

acquire a permanent "set" in the new position which their substance is forced to assume in the thread. In the doubling process the two or more single threads are passed through water, and in order to lay the fibre all one way beneath a pot weight resting upon a strip of cloth from beneath which it passes on to the spindle.

A part of the setting process also depends upon the subsidence of the electrical excitement which is induced in the fibre by the friction to which it is subjected in the process of manufacture. This electrical excitement is often very great in dry frosty weather during winter, and specially in combed yarns, where the fibres are mechanically drawn out through the teeth of the combing cylinders, this excitement causing the threads to assume a wild and hairy appearance, arising from the mutual repulsion of the individual fibres, and which is only removed by leaving the yarn for some time in a moist place such as the conditioning room. This electrical action is sometimes so strong that it gives shocks to the machine attendants, and sparks can be drawn from the frame of the combing machine by placing the knuckles or finger-tip close to it. The best cure is to connect the frame of the machine with a copper wire to the nearest gas-pipe.

When the cotton has been gathered, and the more volatile portions of the oil dried up, there always remains associated with it, and usually on the surface of the fibre, a peculiar wax which has received the name of cotton wax from Dr. Edward Schunk, F.R.S.,[1] who first discovered and investigated its properties. From the fact that when this wax is perfectly pure it is quite insoluble in alkalies, while it is readily so in alcohol or ether, it has been assumed

[1] *Memoirs, Manchester Literary and Philosophical Society*, vol. iv. Third Series, p. 95.

that the wax is really deposited on the surface of the outer sheath of the fibre; and when the cotton is subjected to the action of hot liquid in the bleaching and other processes this wax is simply melted and removed mechanically from the surface. When subjected to the action of strong alkalies, the natural oils and fats of the fibre are saponified, and may be collected by afterwards neutralising the resulting liquid with sulphuric acid.

The wax is composed of:—

Carbon	80·38	per cent.
Hydrogen . . .	14·51	,,
Oxygen	5·11	,,
	100·00	

The composition of this wax appears to differ slightly when derived from different classes of cotton, but the above is the average derived from American cotton. It fuses at a temperature of 186·8° F., and solidifies at 179·6° F., while the wax derived from Dhollerah (Surat) cotton has the same melting-point, but does not solidify until it has reached 177·8° F.

Both these waxes bear a resemblance to cerocine, a wax prepared from the leaves of the sugar-cane, and the Carnauba (*Corypha cerifera*), the composition of which is given as follows:—

	Sugar Cane Wax.	Carnauba Wax.
Carbon . .	81·00 . .	80·36
Hydrogen . .	14·16 . .	13·07
Oxygen . .	4·84 . .	6·57
	100·00	100·00

Dr. Schunk prepared this wax by boiling 500 lbs. of

middling Orleans cotton spun into 20's yarn, so as to remove all mechanical impurities, in a strong solution of soda ash for 7½ hours.

The result was a dark brown liquor which, when heated with sulphuric acid, precipitated a light brown flocculent matter which settled to the bottom of the vessel, and was separated by filtration. When dried and inspissated, a brittle horn-like mass was obtained. American cotton yielded about 0·48 per cent, and Surat cotton about 0·34 per cent. This is given because the author found that the quantity of matter precipitated varied in different kinds of cotton, and also from year to year from the same kind. The oily wax, therefore, apparently being a variable quantity will no doubt affect the spinning qualities of the cotton in different seasons, and also the chemical reactions afterwards, and necessitate different treatment to a certain extent in the preparation for dyeing.

Along with this wax there is also a fatty acid, which is white and solid, and which by analysis has been proved to be identical with margaric acid, which has the formula $C_{34}H_{34}O_4$. There seems reason, however, to believe that this body is really a mixture of two other fatty acids, probably stearic acid, $C_{17}H_{35}.COOH$, and palmitic acid, $C_{15}H_{31}.COOH$, but the quantity obtained from even a large weight of cotton fibre is so small as to prevent their being crystallised out for specific investigation.

Colouring Matter.—Associated with many cotton fibres, especially Egyptian, there is always a certain amount of colouring matter which exists in the form of endochrome, and is irregularly distributed in the fibre and mostly contained in the walls of the fibre immediately surrounding the inner cavity or lumen. In Egyptian cotton this is always sufficient to give it a decidedly

reddish-brown or golden colour, but becomes whiter in direct sunlight. Also, it becomes darker when exposed to moist heat, such as in the steaming process preparatory to doubling.

This colouring matter is soluble in alcohol and destroyed by oxidising agents, but its exact composition does not appear to have been determined.

Dr. Schunk, in the paper above referred to, made a very careful examination of the colouring matter associated with American and East Indian cotton, and found that it was of two kinds, one of which is readily soluble in alcohol, and which he called A,, and the other, which he named B, soluble in boiling alcohol. These two substances gave the following ultimate analysis:—

	A.	B.
Carbon	58·30	57·77
Hydrogen	6·12	6·05
Nitrogen	6·18	8·74
Oxygen	29·40	27·44
	100·00	100·00

He remarks: "It will be seen that the composition of the substance varied, especially as regards nitrogen, much more than it ought to have done supposing it to have been absolutely pure. In consequence of the amorphous nature of the product it is difficult to determine whether the Indian and American cotton contains two distinct colouring matters, both easily soluble in alcohol, and having the same general physical properties, or whether in one or both cases the specimens submitted to analysis, though essentially the same, were not chemically pure. It is difficult to obtain, in a state of purity, an uncrystallisable

resinous body having few characteristic properties, and the results arrived at by the examination of such bodies are seldom satisfactory." From this it may be inferred that, as regards their chemical properties, these colouring matters possess little interest, except the fact that being colouring matters and the cause of the yellow or brown tinge natural to cotton, makes a knowledge of their properties desirable from a practical point of view. The darker shade of colour seen in the "Nankin" cotton is probably due to an excess of these colouring matters existing in the fibre. It is certainly not caused by oxide of iron, since the ash of this kind of cotton contains no more iron than that of ordinary cotton, and the colour is for the most part removed by treatment with caustic alkalies.

In some samples of dark Egyptian cotton the author detected distinct traces of iron, some combination of which with organic matter may be the cause of the very dark shade of colour.

Unchanged Cell-Contents. (Protoplasm and Pectoses.)—From the recent researches in dyeing it seems not improbable that cellulose, as it exists in the cotton fibre, is able without any mordant to enter into union with reagents or colouring matters, so as to form compounds which are sufficiently stable to resist the action of water and other solvents in removing them, although it cannot be said that we have sufficient knowledge of them to determine whether they are true combinations in the same sense as the union between acids and alkaline bases.

This probably arises from the fact that no cotton fibre is perfectly pure cellulose, as it always contains some of the unchanged primary sugar-like carbohydrates which exist as protoplasmic juices or sap, before the first deposition of

cellulose on the cell-wall. It is probable that only in very few fibres is the change of the whole of the cell-contents into cellulose completely effected, and it is these untransformed and unstable compounds which are the active agents in such combinations and not the fibre itself. The analysis given on page 147 shows that there is seldom more than 90 per cent of pure cellulose, and if the organic parts of the fibre only were taken, and unripe fibres, which are found in large numbers in every boll, included, not even as high as this. According to Mangin, the partition wall formed in the highest plants, during cell-division, consists almost entirely of pectose; the next-developed laminæ, the secondary cell-wall layer, of a mixture of pectose and cellulose; and the last-formed, or tertiary layer, almost entirely of cellulose. If the secondary layer of the cell-wall, as in the case of the developed cotton fibre, remains unlignified the amount of pectose increases with age, and tends to strengthen the primary cell-wall. In addition to pectose and cellulose there is also present another allied body—callose, which is insoluble in cuprammonium solution, and is coloured an intense blue with aniline blue and red with rosolic acid. The presence of this callose in the tertiary layer probably accounts for the residuum undissolved when the fibre is treated with cuprammonium, as seen in Fig. 40.

In the earlier stages of the cotton fibre the cell-contents are similar to those contained in the juices of all unripe fruit, comprising a mixture of organic bodies to which the general name of pectose is given, and which has a so far undetermined composition of carbon, hydrogen, and oxygen with various organic acids such as malic, citric, oxalic, tartaric, and tannic acids which give a peculiar roughness and astringency to the juices. This is very marked when

an unripe cotton boll, especially in its early stages, is cut across and tested. Tannic acid, $C_{14}O_{10}O_9$, is always present, and must be specially noted, as it gives a strong coloured reaction with iron salts which are used in the production of ink and of slate and other colours in dyeing.

Pectose itself is quite insoluble in water, but during the changes which occur, under the action of sunlight and air, and in association with the vegetable acids, it is converted into a definite pectosic body, pectin, $C_{32}H_{40}O_{28}$, which readily dissolves in water and gives a viscous solution. As the ripening proceeds a further change occurs, and the pectin is transformed into pectic acid ($C_{16}H_{22}O_{15}$) and pectosic acid ($C_{32}H_{46}O_{31}$), which are soluble in boiling water, and give solutions which, when cooled, yield viscous jelly-like bodies. These changes seem to occur in the unripe juices of the cotton fibre concurrently with the production of cellulose, and can be obtained from infusions of all unripe fibres.

It is not improbable that in bad seasons where there is deficiency in sunlight, a change of these organic acids into sugars and other less chemically active bodies does not occur, and this may account for the weakness of the fibre, since, if left in the fibre unchanged, they may act upon the cellulose and destroy its tenacity by the usual action of these acids, whereas with sufficient sun they undergo change by absorption of oxygen and evolution of CO_2, as for example:—

$$\underset{\text{Tannic Acid.}}{C_{14}H_{10}O_9} + H_2O + 12O = \underset{\text{Fruit Sugar.}}{C_6H_{12}O_6} + 8CO_2;$$

or $$3\underset{\text{Tartaric Acid.}}{C_4H_6O_6} + 3O = \underset{\text{Fruit Sugar.}}{C_6H_{12}O_6} + 3H_2O + 6CO_2$$

The acids in both cases being transformed into fruit sugar as occurs in the ordinary ripening of fruit, the acidity and

astringency, become less as the boll advances towards maturity.

It does not appear to the author that sufficient attention has been paid to these residual products from an industrial point of view. He was struck, when investigating this subject, and using the bolls taken from the cotton plants grown under glass under his own eye, with the wide difference, even in two contiguous bolls, in regard to the degree of ripeness and the number of fully matured fibres which were seen. There is no doubt, also, that the ripening process is really continued after the fibres are plucked from the boll, and that the drying up of the juices which are contained in the unripe fibres, when removed from the seed by the ginning process, even after being packed into the bale, renders them more fit for use than when just gathered; and also that the mechanical process of ginning, by making an intimate mixture of fibres from all parts of the boll, tends to average the degree of maturity and ripeness in all parts of the bale into which they are afterwards packed.

Nitrogen in Cotton Fibre.—Associated along with the cotton fibre there are also small quantities of nitrogen amounting on the average to about 0·345 per cent, but varying in different varieties of cotton, as the following table shows:—

NITROGEN CONTENTS OF COTTON FIBRE

American (Orleans)	0·30 per cent.
Sea Island	0·34 „
Bengal (Surat)	0·39 „
Rough Peruvian	0·33 „
Egyptian (white)	0·29 „
„ (brown)	0·42 „

There is reason to believe that the quantity of nitrogen varies in different years, because analyses made in America show a considerable difference in this respect, and are given for Upland cotton as maximum, 0·54; minimum, 0·20; average 0·34.[1]

This nitrogen probably forms part of the albuminous matter which was found by Dr. Schunk to be contained in the fibre, and it probably arises from the presence of the unchanged protoplasm which, as seen above, remains as a cell-content in the unripe fibres. In some cases it probably arises from, or is increased by, the existence of nitrates derived from the soil along with other mineral constituents.

Mineral Constituents of Cotton Fibre.—The mineral matter usually consists of phosphates and chlorides of potash, soda, and magnesia, small quantities of lime, and the sulphates of these bodies in combination with the various organic constituents of the fibres.

The mineral constituents were quantitatively examined by Dr. Ure, and he found that in a sample of Sea Island cotton they amounted to very nearly 1 per cent of the weight, and yielded, on analysis, the following results:—

	Per cent.	
Carbonate of potassium .	44·80	soluble in water.
Chloride ,, . .	9·90	,, ,,
Sulphate ,, . .	9·30	,, ,,
Phosphate of lime . .	9·00	insoluble in water
Carbonate ,, . .	10·60	,, ,,
Phosphate of magnesia .	8·40	,, ,,
Peroxide of iron . .	3·00	,, ,,
Traces of alumina and loss .	5·00	,, ,,
	100·00	

[1] Bulletin No. 33, U.S.A. Dept. Agriculture, 1896.

These results were obtained from cotton after scutching and carding, and therefore all mechanical impurities, such as sand and other adhering matter, would be removed.

A more recent determination is that by Davis, Dreyfüs, and Holland,[1] who, after deducting the sand, analysed the uncleansed fibre. A portion of twelve different varieties of cotton were taken and burnt to a white ash at as low a temperature as possible. The ash was then collected, mixed, and analysed with the following results:—

	Per cent.	
Carbonate of potassium .	33·22	soluble in water.
Chloride ,, .	10·21	,, ,,
Sulphate ,, .	10·02	,, ,,
Carbonate of sodium . .	3·05	,, ,,
Phosphate of magnesium .	8·70	insoluble in water.
Carbonate ,, .	7·81	,, ,,
,, of calcium . .	20·26	,, ,,
Peroxide of Iron . .	0·40	,, ,,
	100·00	

The same analysts also conducted a series of experiments to determine the amount of ash arising from sand and mineral matter contained in different classes of cotton.

The samples were taken out of bales immediately upon their arrival in Liverpool, and therefore before undergoing any cleansing process, and these gave the following results:—

ASH FOUND IN UNCLEANSED COTTON

Dharwar (Surat) . . .	4·16 per cent.
Dhollerah ,, . . .	6·22 ,,
Sea Island	1·25 ,,

[1] *Sizing and Mildew in Cotton Goods*, p. 16.

Peruvian (soft) . . .	1·68 per cent.
,, (rough) . . .	1·15 ,,
Bengal (Surat) . . .	3·98 ,,
Broach (saw-ginned) . .	3·14 ,,
Oomawuttee . . .	2·52 ,,
Egyptian (brown) . . .	1·73 ,,
,, (white) . . .	1·19 ,,
Pernambuco . . .	1·60 ,,
American	1·52 ,,

It will be seen from these figures that some varieties are very low in ash, such as Sea Island, rough Peruvian, and white Egyptian; while others of them, and specially the Surat cottons, are very high, as in Dhollerah cotton, where large quantities of sand were mixed with the fibre. The author found that the quantity of dust and foreign matter found in the cotton from the bale varied greatly in different seasons and in the same class of cotton.

As a rule the ash should not much exceed 1 per cent, and if it does the excess will probably be mechanical impurities, and can be removed by the scutching process.

The variation in the mineral constituents of the cotton fibre, during indifferent years, is clearly indicated in the following table extracted from the U.S.A. Agricultural Bulletin, No. 33, page 90, taken during three different years.

[TABLE

MINERAL CONSTITUENTS OF COTTON FIBRE

TAKEN IN DIFFERENT YEARS

Class of Cotton.	Water per cent.	Ash per cent.	Nitrogen per cent.	Phosphoric acid per cent.	Potash per cent.	Lime per cent.	Magnesia per cent.
Upland Cotton .		0·93	...	0·11	0·28	0·16	0·03
,,	1·72	1·25	.	0·07	0·44	0·12	0·12
,,		1·50		0·06	0·44	0·11	0·03
Sea Island .		1·31	..	0·16	0·28	0·18	0·06
,,	.	1·50	..	0·17	0·36	0·26	0·02
,,	.	1·00		0·09	0·48	0·11	0·03
Upland Cotton .	..	1·14	. .	0·04	0·47	0·07	0·10
,,		1·50	0·54	0·06	0·44	0·11	0·03
,,	6·72	1·50	0·28	0·07	0·64	0·16	0·11
,,	6·77	1·80	0·20	0·05	0·85	0·15	0·16
Minimum . .	4·72	0·93	0·20	0·05	0·28	0·07	0·02
Maximum .	6·77	1·80	0·54	0·18	0·85	0·48	0·17
Average . .	6·07	1·37	0·34	0·10	0·46	0·19	0·08

According to Calvert, cotton samples from different countries contained phosphoric acid, HPO_3, soluble in water as follows:—

Egyptian	0·055 per cent.
American (Orleans) . .	0·049 ,,
Bengal (Surat) . . .	0·055 ,,
,, ...	0·027 ,,
Carthagena . . .	0·043 ,,
Cyprus	0·050 ,,

Water or Aqueous Contents of Cotton Fibre.—It will be seen from looking at the formula for the simplest expression of cellulose that the hydrogen and oxygen atoms are present in the cellulose molecule in the proportions to form water, as will be clearly seen if we write $C_6H_{10}O_5$ as $C_6(H_2O)_5$. It is known, however, from many of the re-

actions that this is not the form in which the atoms are arranged, and it therefore appears that any moisture which is usually associated with cellulose, under ordinary conditions, is not an integral portion of its molecular structure, but simply mechanically associated, or present as water of crystallisation along with the mineral impurities, or as part of the liquid cell-contents, or else in some very feeble and hitherto unrecognised form of chemical combination, along with the cellulose itself, as water of hydration. This is an important point, because it must be remembered that along with the cotton fibre there must always be more or less water or moisture present.

In the new cotton crop this is more abundant than when the bales have been left for some time in a dry warehouse, so that any water which is only mechanically associated has had time to evaporate; and there is strong reason to suppose that in some instances, both in America and other countries, the fact that the water costs little and weighs much is not altogether forgotten.

Apart, however, from any addition of water with fraudulent intent, there is always a certain quantity present, which passes off when the cotton is exposed in a loose condition in a room or warehouse at about 60° F. This quantity varies with the seasons from 1 to about 8 per cent in the new crop, and rather less as the season advances. Above 8 per cent of moisture, however, seems to be an excessive quantity, even in new crop cotton; and when more than this it is either the result of a wet season and the cotton having been packed without drying, or else it has been artificially added. Some authorities have contended, like the editor of the *Indian Textile Journal*, that cotton will lie much closer in the bale and resist wear and tear of transit much better if packed in a fairly moist condition, and be

better for spinning purposes. This may, however, possibly be so, for if the fibre when packed is too dry, the ripening process in the bale already spoken of may not take place, as a certain amount of moisture is essential for the change.

When by natural drying the excess of moisture is removed, however, there is still a further quantity which evaporates off when the fibre is subjected to a higher temperature. This amount may be looked upon as essential and not artificial. It forms, in fact, what is known as water of hydration, which seems to be associated with the fibre and united to it in a kind of feeble chemical combination, and depends probably upon the same cause as that which enables fibres to attract and retain colouring matter, or absorb gases in large proportion, compared with their own volume. It may, however, partly arise from water absorbed by those constituents which are removed as water extract by boiling, and which are far more hygroscopic than the fibre itself. If this water is removed, by subjecting the fibre to a high temperature, it is not speedily replaced when the fibre is left in the ordinary conditions of temperature, and the fibre, until this water is replaced, always presents a hard, harsh, and wiry feeling, and looks wild and hairy.

In order to test the quantity which this water of hydration represents, the author exposed a number of cotton samples for some weeks in a room where the temperature was maintained at a heat of 60° F. Upon subjecting these samples to a temperature of 212° F. he found that they lost from 6 to 8 per cent; and when they were replaced in the same room for some days they gradually regained all the weight which they had lost, showing that the fibre possesses the power of attracting

moisture from the atmosphere when drier than the surrounding air. This degree of attraction varied with the hygrometric condition of the air.

All practical spinners have experienced this, on the large scale, when the dry east wind has been replaced by a moist south or south-west wind; and the yarn in the mill has weighed heavier, although no alteration has been made in the change wheels which determine the counts in the spinning. In the same way, when damp weather has been succeeded by dry or frosty weather, the yarn has come round lighter, to an extent varying from an almost imperceptible quantity up to 5 per cent.

When the same samples were subjected to a higher temperature than 212° F., viz. 240° F., a temperature so hot and dry as to only just prevent the yarn from being singed or charred, a further quantity of moisture was lost, varying in addition to that lost up to 212° F. by about 6 to 7 per cent. The fibre, therefore, if raised from its normal temperature up to the highest point before charring will lose 12 to 14 per cent of its weight. This we may consider the limit of the moisture, including this 6 to 7 per cent of water of hydration, and when this is all driven off, and the fibre placed in the usual condition, it never, except artificially watered, quite regains what it has lost. About 2 to 3 per cent seems to be due to the drying up of certain cell-contents, which have not the power of replacing the moisture. Another cause may also be in operation, viz. a change under the action of the heat of the wax and other oleaginous matter, which on being inspissated assumes the form of a resinous rather than waxy body, as, if the wax is dissolved from the fibre and then heated, it can be made quite hard and brittle. With elevated temperature, therefore, this protecting wax becomes far more impervious to

moisture, and probably also cements firmly together the cellulose layers of which the cell-wall is composed. Some chemists have supposed that the power of the cotton fibre to attract moisture depends entirely upon the tubular structure of the fibre, so that it is only an instance of capillary attraction; but the fact that, if we precipitate the cellulose from its solutions in an ammonio-cupric-oxide solvent, the amorphous jelly, which can have no capillary attraction, also possesses this property, militates against this view, and seems to indicate that it is a true chemical affinity.

The question of the quantity of water which is normally present in cotton is of great commercial importance, and a standard has been adopted now by all testing-houses which differs by only ½ per cent from the above results, which were obtained by the author in 1882 and published in his work on the cotton fibre, and this extra ½ per cent is probably allowed, so that the standard may appear not so exacting to the seller and reasonable and fair to the purchaser.

In these testing-houses the weight taken is usually two to three pounds, and this is dried in a specially constructed oven, as will be seen in Fig. 49, arranged so that the yarn or cotton can be weighed when in the hot atmosphere of the oven, and the drying process noted as it proceeds. The oven shown in the figure is one of those in the Manchester Chamber of Commerce testing-house. The wire basket in which the material to be dried is placed is suspended in the oven by the wire depending from the beam of the balance. The oven is heated by gas, with a double lining up which the hot air passes, and fitted with a thermometer, so as to read the temperature.

The following table shows the standard allowance of

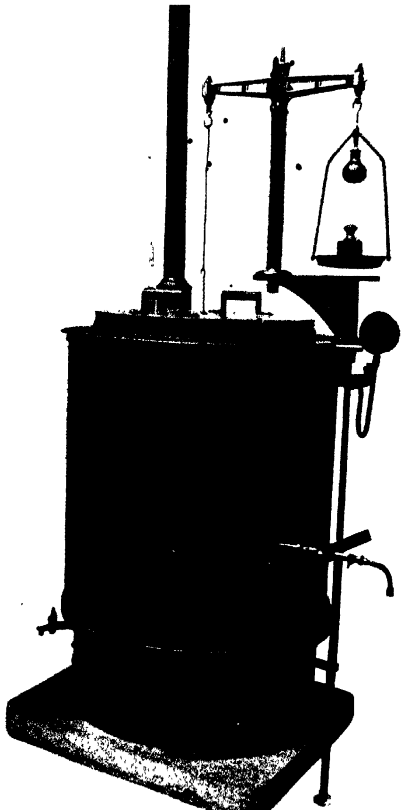

FIG. 49.—Drying Oven, Manchester Testing-House.

moisture adopted for cotton and other materials in Manchester and Bradford:—

TABLE OF WATER ALLOWANCE

Material.	Manchester.	Bradford.
	per cent.	per cent.
Raw cotton . . .	$8\frac{1}{2}$	$8\frac{1}{2}$
Cotton yarn . . .	$8\frac{1}{2}$	$8\frac{1}{2}$
Worsted yarn .	$18\frac{1}{4}$	$18\frac{1}{4}$
Carded woollen yarn .	17	$18\frac{1}{4}$
Tops combed with oil .	17	19
Tops combed without oil	17	$18\frac{1}{4}$
Noils	17	14
Scoured wools . .	17	16
Hemp and flax .	12	16
Jute	$13\frac{3}{4}$	16
Shoddy yarn . . .	13	16
Silk	13	16

The above standards have been accepted by all testing houses in Great Britain, the Continent, and America, and no other competing standards can be said to exist.

Referring to the question of the temperature at which yarn should be dried, the following is copied from the notes on testing issued by the Manchester testing-house, and may be taken as authoritative: "The standard is based upon what is known as the 'Regain system,' whereby it is supposed that if 100 parts of absolutely dry cotton be exposed to the ordinary conditions of the air, $8\frac{1}{2}$ parts of moisture will be absorbed. The drying temperature, to which the cotton is subjected when in bulk, is from 212° F. to 230° F. This $8\frac{1}{2}$ regain is not, however, strictly $8\frac{1}{2}$ per cent regain, because absolutely dry cotton becomes $8\frac{1}{2}$ heavier by exposure to air, then

$$108\tfrac{1}{2} : 8\tfrac{1}{2} :: 100 : 7{\cdot}834,$$

which represents the percentage of gain."

Reference has been made to the exception sometimes taken to the drying of the cotton at 212° F., the temperature adopted by the testing-house (Manchester); and since this is a most vital part of the drying process it seems advisable to state further what is to be said for and against such a standard. It may at once be said that this temperature is some 10° or 15° F. lower than that used at the large Continental conditioning-houses during half a century, and it is not clear how the testing-house came to adopt 212° F. Since, however, objection is never made in this district against drying at low temperature we need not consider whether 212° F. is too high a temperature. The process of drying is an artificial one, and has been adopted, not because it attempts to take out the moisture without altering other conditions, but because it is a ready means of reducing the weight to a fairly constant condition. It must be understood that cotton will lose water at all temperatures up to the point of charring, but there is a wide range of temperature above and below 212° F., where the loss increases very slowly with the temperature, as will readily be seen from the fact that if cotton has once been heated for a few hours to about 160° F., further heating to even 220° F. will only cause a further loss of moisture of about 5 per cent. We speak of cotton as "absolutely dry" when dried at 212° F., though in one sense it may be said that moisture is still contained in it; at any rate it will lose moisture if heated still higher.

The length of time necessary to dry samples is frequently stated; for such rough methods as those under consideration three hours is sometimes given. With any properly constructed oven a much less time than this should be ample, so long as the sample does not exceed one or two pounds.

There are serious objections to extending the time of drying, for instance the increase of weight known to follow protracted heating of fibres. (The cause of this does not seem to be exactly known, unless at that temperature heating causes oxidation of some of the constituents of the fibre.)

Weighing the sample after leaving the oven is anything but reliable, making the exact results a matter of chance. If the sample be weighed immediately after it is removed from the oven, it causes an upward current of air at the side of the scales, thus giving the weight too light; and if left to cool before weighing, it will absorb moisture from the air and weigh too heavy. No guess can be made at correct results, and the proper alternative is to use such ovens as those at the testing-house, where the weighing is conducted within the hot atmosphere of the oven.

The following table shows the effect of drying at different temperatures. Two lots of yarn were dried for about three hours at about 160° F. The details of the test are as follows:—

[TABLE

Time.	Sample I.	Temperature.	Sample II.	Temperature.
	lbs. ozs. drs.		lbs. ozs. drs.	
1·30 (before drying) . .	2 7 5½	...	2 7 14	...
2·7 (during drying) . .	2 4 7½	154° F.	2 4 13	162° F.
2·17 ,, . .	2 4 1	155° F.	2 4 11	162° F.
2·30 ,, .	2 3 11½	156° F.	2 4 8½	152° F.
3·5 ,, .	2 3 10	158° F.	2 4 6	152° F.
3·19 ,, . .	2 3 9	160° F.	2 4 5½	152° F.
3·28 ,, . .	2 3 9	...	2 4 5½	159° F.
3·50 ,, . .	2 3 8¼	159° F.	2 4 5½	158° F.
4·50 ,, . .	2 3 8½	158° F.	2 4 4¾	158° F.
Moisture lost at 160° F.	9·57 per cent.	...	8·97 per cent	.
4·37 (during drying) . .	2 3 7¼	180° F.	2 4 4	189° F.
4·48 ,, . .	2 3 5¼	206° F.	2 4 2½	208° F.
4·1[illegible] ,, . .	2 3 5	214° F.	2 4 1	213° F.
5·10 ,, . .	2 3 5	214° F.	2 4 1	214° F.
Moisture lost at 212° F.	10·25 per cent.	...	9·56 per cent	..
5·30 (during drying) .	..	...	2 4 0¾	230° F.
Moisture lost at 230° F.	...	..	9·60 per cent.	...

The temperature was raised to 230° F. at 5·12; neither of the samples showed any sign of scorching or discoloration.

Conclusions.—That drying at 160° F. is a process requiring at least two hours' exposure, under the best possible conditions, and when the sample does not exceed 2 lbs., the difference between drying at 160° F. and at 212° F. seems to be that the latter process gives from 0·5 to 0·75 per cent more moisture or apparent moisture. If the samples had been dried at 212° F. from the commencement, not more than forty minutes would have been necessary to give a constant weight.

It is clear that drying at 230° F. in a properly constructed oven has no scorching effect. We may add that if the

temperature of drying is accidentally less than 160° F. the process is seriously retarded.

There seems to be no reason for drying at a lower temperature than 212° F., but every reason for adopting this or a slightly higher temperature.

CHAPTER XI

STRENGTH AND VARIETY IN COTTON FIBRES

FROM an industrial point of view, one of the most important points in any fibre is that it must possess a certain, and as far as possible, a uniform, strength when subjected to tension. This is necessary because, when made into yarn, and specially where used in making warps, the tension upon the yarn is often very great, and failure arising from the irregularity in strength produces defects in the goods which may render them unmerchantable.

As the strength of the thread ultimately depends on the strength of the individual fibres of which it is composed, it is of importance to see the strength of the fibres of various classes of cotton, and the variation in the strength of fibres of different degrees of development. The strongest fibres, as may be expected, are those which are fully developed and most robust.

Every boll of cotton contains fibres in every degree of development, and in this respect they seem to vary considerably in different parts of the boll.

As a rule those fibres always appear to be most perfect which, from their position on the boll, have come most under the influence of the sun and air, while those parts of the boll which lie underneath, and have been shaded and

enclosed, present the largest number of undeveloped fibres and abnormal growths. It would have been interesting to have instituted a series of experiments to determine the strength of fibres of different degrees of development and ripeness, but it is impossible to do this. The same result, however, is no doubt obtained by taking fibres at random out of any individual boll, the fibres of which seem, after examination under the microscope, to present an average number of these fully matured and well developed.

Strength of Individual Fibres.—The following are the results of the testing of a number of individual fibres of Surat, American, and Egyptian cotton, each of good quality, which were taken at random from a small sample of each class of cotton, and tested on a lever machine with a sliding weight, which was specially constructed for the author. These samples, before testing commenced, had been exposed in a room to a temperature of 65° F. for twenty-four hours.

[TABLE

STRENGTH OF SINGLE FIBRES OF COTTON

MEAN BREAKING STRAIN IN GRAINS

No. of Experiment.	Egyptian.	American.	Surat.
1	140 grains	88 grains	168 grains
2	100 ,,	156 ,,	104 ,,
3	98 ,,	114 ,,	186 ,,
4	136 ,,	99 ,,	102 ,,
5	183 ,,	125 ,,	158 ,,
6	85 ,,	85 ,,	99 ,,
7	152 ,,	162 ,,	178 ,,
8	128 ,,	140 ,,	166 ,,
9	97 ,,	92 ,,	104 ,,
10	114 ,,	116 ,,	123 ,,
11	128 ,,	98 ,,	114 ,,
12	79 ,,	164 ,,	165 ,,
13	85 ,,	172 ,,	184 ,,
14	116 ,,	154 ,,	102 ,,
15	154 ,,	130 ,,	168 ,,
16	104 ,,	102 ,,	94 ,,
17	98 ,,	96 ,,	172 ,,
18	138 ,,	165 ,,	103 ,,
19	156 ,,	123 ,,	168 ,,
20	83 ,,	94 ,,	154 ,,
21	116 ,,	160 ,,	113 ,,
22	140 ,,	144 ,,	108 ,,
23	79 ,,	102 ,,	178 ,,
24	158 ,,	168 ,,	165 ,,
25	170 ,,	154 ,,	113 ,,
Highest .	183 grains	172 grains	184 grains
Lowest .	79 ,,	85 ,,	94 ,,
Average .	122 grains	128 grains	140 grains

This shows the great irregularity in the strength of individual fibres, and the average given is the mean of the whole, and not of the highest and lowest, although it is singular that the mean of the highest and lowest in the American and Surat respectively is 128 and 139, which is practically the same mean as arrived at for the whole, while in the Egyptian it is 131, or considerably

higher than the mean of the whole, which indicates that there is in this cotton greater average irregularity.

A similar test was made in another year of the same general character, but the results were different. There seemed to be in each of them about the same extreme variation, but the average strength of the fibres was as follows: Egyptian 131, American 138, and Surat 143. In this year the Egyptian crop was very good.

Charles O'Neil, in a paper contributed to the Manchester Literary and Philosophical Society, gives a number of experiments, which he made to test the average strength of different classes of cotton, which he arranged as follows:—

	Mean Breaking Strain.
Sea Island (Edisto) . . .	83·9 grains
Queensland (Australian) . .	147·6 ,,
Egyptian	127·2 ,,
Maranham	107·1 ,,
Benguela	100·6 ,,
Pernambuco	140·2 ,,
American (Orleans) . . .	147·7 ,,
,, (Upland) . . .	104·5 ,,
Surat (Dhollerah) . . .	141·9 ,,
,, (Comptah) . . .	163·7 ,,

It appears, therefore, that certain classes of Surat carry the highest weight, and next in order follow American, Australian, Brazilian, and Egyptian, while Sea Island comes last. He makes the average strength of Egyptian considerably greater than the author did in the first test, as given in the table, but less than the second, also the Orleans cotton is stronger, but the average of the Orleans and Upland is 126, which closely agrees with the author's

result, 128. The average of his Surat is 152 against the author's 140.

To make a fair comparison of the relative strength, it is necessary to compare the breaking strains with the relative diameters of the respective fibres, when it will be seen that the fibre which carries the highest strain has also the largest diameter, and, therefore, the largest sectional area to resist the strain. In proportion to the sectional area, however, the Egyptian cotton is relatively the strongest of them all, because, while its diameter is only 0·0000015, or $\frac{15}{1,000,000}$ths of an inch larger than the Sea Island fibres, it carries 43·3 grains more, and while it is 0·000189, or $\frac{189}{1,000,000}$ths of an inch smaller in diameter than Surat, it only carries 36·5 grains less. In proportion to its diameter it ought to carry considerably less than it does, for if the fibres were perfectly round and solid, the Surat would have very nearly twice the sectional area of the Egyptian fibre, which should therefore only carry about 82 grains, whereas it carries 127 grains.

It follows from a simple mathematical law that the strength of the fibre will vary with the sectional area of the tube walls, and those fibres, where the ripening process is complete and the deposition of cellulose layers carried on until the central cavity becomes a mere point, will present the greatest resistance to any force which tends to tear the tube in sunder, as well as prevent the creasing of the fibre and the collapsing of the walls, which are often accompanied by a breaking of the walls and fracture of the fibre.

This is the usual experience with other materials. If a ribbon of paper be taken and stretched perfectly parallel it will, even if only very thin, carry a considerable pressure; but if the pressure is thrown unequally on one side it rends

immediately; for the slightest tear in the edge causes it, instantly, to slit across. So with the flattened, thin, unripe cotton fibres. The attenuated walls of the tube offer no support to the edge, and rupture is the result of the slightest pressure; while in the full mature and ripened fibres, the thicker and denser walls resist the collapse of the tube and tend to equalise the strain all round. In breaking a fibre under the microscope it is not easy to say which part gives way first, but from a number of experiments the process seems to be as follows.

Fracture of Fibres.—When subject to tension the walls have a tendency to collapse, and since no fibre is perfectly round, they always, when subjected to longitudinal strain, tend to depart more and more from the cylindrical shape. When the flattening process has gone so far as to obliterate the whole of the central opening, the extreme outer structureless pellicle seems to suffer rupture first, and the inner parts of the tube seem to slightly extend and draw out, and then the whole completely severs. In some large fibres, and specially after the cotton had been nitrated, the inner walls seemed to indicate a distinct series of cellular layers, the ends of which, one within the other, remained in the form of fibrous masses with a ragged edge. Dyed fibres, where the nature of the colouring matter tends to form small crystals within the central cavity or lumen, are easily fractured, because although the fibres are not directly weakened by the action of the dye, when the cell-walls are forced in by the tension they come in contact with the edges of the crystals, which cut the inner wall, and from this lesion the fracture quickly extends and the fibre ruptures.

It has been seen in the foregoing chapters that, even in the same boll of cotton, there is a very great degree of

variation in regard to the length, diameter, strength and degree of ripeness in the individual fibres, and that all these various characteristics depend upon conditions which are to a large extent (apart from the specific nature of the fibres themselves, which is derived from the character of the seed which is sown) dependent on external influences, and especially those which are climatic in character, such as rain, sun, and air, and the variation in the seasons and relative freedom from disease, or the ravages of insects, both of which differ from season to season. In some seasons, and specially where the cotton has been packed damp, the fibres are attacked by a fungus growth, a form of mycelium, the spores of which, entering the lumen or central space of the fibres, germinate there in the form of long spiral threads, which wind round inside the tube and feed upon the unchanged juices and the cellulose walls, and this leads to tendering and, finally, to the complete destruction of the fibre. These spiral threads have often been mistaken by microscopists for spiral structure in the fibre walls, but careful examination reveals the difference.

For technical purposes the utmost regularity is desirable, but all who are engaged in the cotton trade know how different the cotton is in all these characteristics, and the difficulty which is experienced in always making the same quality of yarn. It is interesting, therefore, to examine the differences observable as

Variation in the Character of Fibres from the same Plants grown in different Years.—It is a well-known fact that botanists are able to determine the character of the various seasons, during the lifetime of a tree, by the nature of the rings presented in the trunk by the section of any exogenous or dicotyledonous tree, the

space between the rings being widest in those seasons where abundance of water and heat has stimulated the development of the woody fibres, whereas in dry seasons, when the growth of the plant has been checked, the distance between them is smaller. In the same way a good or bad harvest, either of cereals, leguminous plants or fruit, is the resultant of the sum of the rain and sunshine, heat and cold, and other meteorological conditions with which the plants have been favoured or against which they have had to contend.

Cotton is no exception. Some years are distinguished by good and some by bad crops, and as might naturally be supposed, the years when the crop is most abundant are also distinguished by the quality of the cotton being generally the best, because the same conditions which favoured the production of a large quantity of bloom also favoured the ripening and maturing of the fibres.

Mechanical Variation in different Seasons.—All who are practically engaged in the manufacture of cotton know that the fibre of the cotton in one year frequently differs from that of another in many important particulars. During some seasons it is much drier than in others, and it also differs to a marked degree in the quantity of natural oil which is associated with the fibre, and this has undoubted effect upon the spinning properties which it possesses and the relative strength of the yarn. This natural oil imparts a kindness and suppleness to the fibres in working, and prevents the drying up of the cell-walls until they become hard and crack, while its absence imparts a degree of harshness and want of pliability to the fibres which very naturally interfere with the ease with which the fibres can be manufactured into yarn.

The above changes, which vary from season to season,

may be considered as relating to the mechanical structure of the fibres, and interfere with its size, such as length and diameter, and also with its strength, which is often very marked, from season to season, so that in some years it is found impossible to obtain yarn of the same strength as in the season before without going to a considerably higher classification of cotton for the purpose of spinning the same counts of yarn.

Chemical Variation in different Seasons.—These variations are quite as much marked as those which affect the physical properties of the fibres. These changes affect the degree of absorption in the fibre for liquids by altering its dialysing properties, and also the nature of the cell-contents.

When the changes and growth of the fibre, in a good season, are complete, as in the case of all the perfectly matured and ripe fibres, all the acid and astringent juices are perfectly changed into cellulose, callose, sugar, or oil, and are therefore neutral to the various dyeing and other materials with which they are afterwards inpregnated during the dyeing and finishing processes, whereas, when the want of sun and excess of moisture has prevented the full maturity and change, these various bodies are only partially formed, while those which are unchanged remain in the fibre and act as reagents, and especially in regard to the tannin-like astringent substances, which give a distinct chemical reaction with many metallic salts, such as those of iron.

One season some years ago, when very fine Egyptian yarns were being used in the Bradford trade, and the run was principally upon light and delicate shades, the author was called in to more than one arbitration, where individual fibres and masses of fibres had turned black or dark shades in all those colours where salts of iron w

dyeing process, and from the appearance of the dark colouring matter in the cell-walls of the individual fibres there was no doubt that this defect arose from the presence of tannin, or some such allied body, in the juices of the fibres, and which, from the want of sun and prevalence of mists during the growing season, had never been changed into neutral bodies, and they therefore entered into combination with the iron salts and gave these dark shades, which it was impossible to remove out of the yarn, before dyeing, by any of the usual processes of washing and cleaning of the yarn preparatory to dyeing. The next season, with the same shades and goods, the defect hardly ever occurred, and it had not done so, under the same use, during the season before. The "kempy" structure, in which the fibre appears to be built up in such a manner that it forms a solid, apparently structureless mass, in which the part of the fibre so affected does not seem to be possessed of absorbent qualities, also is much more abundant some seasons than others, and also the coarser varieties of cotton, such as Surat and rough Peruvian, seem to be more liable to this defect, which seldom occurs in Egyptian or Sea Island.

The chemical changes in the fibre being the means employed in building up the cell-walls, it will easily be seen that if they are not accomplished, many of the mechanical qualities must necessarily also suffer, and it is observed that it is always in the same seasons where the chemical defects are apparent, that the mechanical faults such as deficiency in strength, want of length, and unformity in staple, so that it does not draw out with a "square edge," always occur, and therefore there is more difficulty in spinning and more waste made in the The above charactu Strictly speaking, no two cotton

crops are exactly the same, and each requires almost a distinct difference in manipulation. Fortunately, cotton being grown over such a wide area of the earth's surface, the crops are seldom bad ones in every district, and the spinner can, therefore, at the commencement of each season, obtain a variety of cotton of different grades to mix together and so minimise these variations. The differences in the character of the cotton fibres during different seasons, from the same plants, are not so great as the specific differences which arise from the variation in the character of the fibres which are obtained from different species of cotton, and which are grown in different countries. In selecting cotton for manufacturing purposes these specific differences are of great importance, and it is therefore necessary that an examination of these should be carefully made and noted.

Difference in Fibres grown in different Countries. -Generally there is a family likeness in all cotton fibres, from whatever country they come, but these characteristics are modified by the special climatic and other conditions pertaining in the various countries, and which are sufficient even to alter the character of fibres grown from different species.

As classified by the length of the staple the cottons may be arranged as follows :—

1. Sea Island, including Australasian and Australian cotton.

2. Egyptian cotton.

3. Brazilian and South American States.

4. American grown in various parts of the United States, Sea Island excepted.

5. East Indian or Surat cotton, including Burma, the Straits Settlements, China, and Japan.

1. *Sea Island cotton* is the most perfect form of cotton fibre, and plays the same part in the cotton world that the long-stapled Australian wools do in the worsted trade. For length of staple, small diameter, general excellence, silkiness, and uniformity in length and strength, it stands unrivalled, and, grown as it is, in a semi-tropical climate, where great extremes of temperature during the cotton-growing season are almost unknown, it always commands the highest price and can be spun into the finest numbers. The proportion of fully developed fibres in relation to the whole number in the boll is the greatest, and the fibres usually present the appearance of a rounded and well-fed structure, with thickened edges and high lustre, which probably arises from the fact that since the cell-walls are so thick and firm, the outer pellicle is fully distended and presents fewer wrinkles and creases on the surface than any other. The fineness of this cotton may be judged from the fact that it has been spun into counts as fine as 2150 hanks to the pound, so that one pound of this yarn would be upwards of 1000 miles in length.

Fig. 50 shows a few of the characteristic fibres of Sea Island cotton magnified 180 diameters, in which the general perfection and lustre of the cotton are clearly seen.

2. *Egyptian cotton* stands next to Sea Island in possessing all the most desirable qualities, and since the introduction of the combing machine, which enables the irregularities in the fibres to be adjusted by the removal of all which fall below a certain standard of length, it has been used in the production of the finer numbers of yarn up to 200's.

Egyptian cotton is also usually distinguished by a golden or brownish yellow colour, which arises from the presence of an endochrome associated with the cellulose

which forms the cell-walls. The introduction of American seed into Egypt has produced a white variety, which nevertheless, although grown in the same soil and under the same conditions, does not fully partake of the best qualities of the Egyptian cotton, but retains many of those which are peculiar to the American. There are always associated with Egyptian cotton, and specially at the tapered end of the seed, more or less of the short fibres, already mentioned as existing in the boll and forming a sort of undergrowth

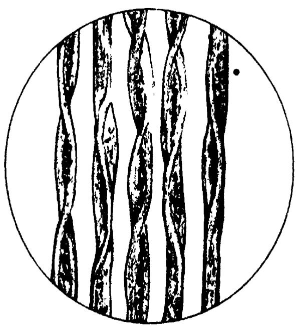

FIG. 50.—Fibres of Sea Island Cotton. × 180 diameters.

to the longer fibres, and these short fibres coming off in the process of ginning, render the general character of the fibre less clean and necessitate a more careful attention in the carding process, though they are entirely removed when the fibre is combed, than when American cotton is used. If left in the sliver these short hairs, which are usually associated together in small clusters, form what are called "neps," which appear on the surface of the thread when spun into yarn. These short fibres were shown in Fig. 41.

There appears to be a difference, in different years, in the quantity of this undergrowth, and also in different lots of cotton grown in the same year. The causes upon which it depends are not known, but it is always present more or less. It seems also that a smaller quantity of these shorter fibres are removed when the gin used is a roller-gin than when a Macarthy gin is employed. The saw-gin is never used for Egyptian cotton, on account of the great damage which it does to the fibre.

It has already been seen that Egyptian cotton, in proportion to its sectional area in the fibre, is considerably stronger than American, or indeed any other cotton, and as it possesses a silkiness of surface and suppleness in a high degree, being in this respect almost equal to Sea Island, it is used for the large mass of single yarns which lies beyond the range of American cotton, but which must be produced at a price less than if Sea Island was used. The white Egyptian seems to be less affected by variations in the season than the brown, and this greater uniformity in yield has tended to extend the cultivation of the white against the brown variety. Similar counts of yarn, spun out of American and Egyptian cotton respectively, when examined under the microscope, seem to differ considerably in character, arising from the differences in the two fibres.

The Egyptian cotton lies closer, the fibres themselves being more flexible and capable of turning a sharper angle with less disturbance of the molecular structure of the fibre and less tendency to rupture. On account of the less diameter of the fibres, the threads of the same counts are finer with the same twist in—that is to say, less in diameter, and yet possess an equal weight of material and a larger number of fibres in the cross-section of the thread.

The regularity in the individual fibres of fully ripe

Egyptian cotton is also greater than in any other class of cotton, and this alone is a great element of strength, because the fibres are more evenly distributed in the yarn and the ability to carry strain therefore more uniform. The brown colour renders the cotton less available for mixing with other cottons, and as it varies also in different seasons great care has to be exercised when new crop cotton comes into the machinery to prevent shadiness

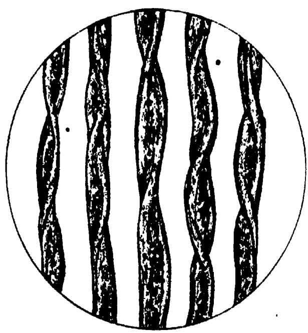

FIG. 51.—Fibres of Egyptian Cotton (Brown). × 200 diameters.

arising from this cause; and care must also be taken at the beginning of each season to see, in the case of warp yarns, that the warping bobbins are run down or cleaned off altogether, so as to prevent the yarn of one season being mixed with that of the next, or otherwise stripy places are sure to appear in the goods, and this effect can only be removed by giving a full bleach to the yarn before dyeing, as it will show even with black when the goods are finished.

Fig. 51 gives an illustration of Egyptian cotton fibres taken from a sample of good brown Gallini, and this may

be compared with Fig. 52, which represents the fibres of white Egyptian.

3. *Brazilian or Peruvian cotton*, which stands next to Egyptian in point of length and other characteristics, forms a convenient connecting link between it and American. It possesses in some respects many of the qualities of the former, but it does not possess the same regularity either in length or diameter of the fibres. Some

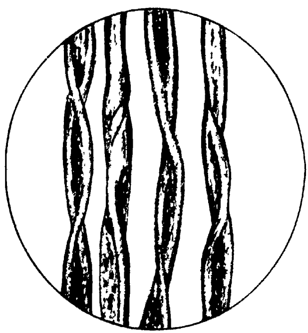

FIG. 52.—Fibres of Egyptian Cotton (White). × 200 diameters.

classes of this cotton, such as rough Peruvian, have a harsh wiry feeling, and, while having considerable staple, have a strong, well-developed fibre. Whether it is from the nature of the conditions under which it is grown, or the variability of the climate, it is subject to great variations from one season to another, and the lots are often only imperfectly ginned and mixed with portions of broken seed. Too great stress cannot be laid upon the necessity of care and attention in this respect in the district where the cotton is grown, as the breaking up of

the fibre or the seeds to which it is attached renders the cotton far less suitable for the high class of manipulation which is now demanded, and when these avoidable imperfections are added to the frequent irregularity of the fibre arising from natural causes, they present great difficulty in the use for technical purposes. These rough cottons add a peculiar loftiness to the yarns into which they are spun, arising from the more rigid character of the fibres, which, unlike Egyptian, cannot easily be bent in small curves, and this gives fulness and considerably increases the elasticity of the yarn.

Some of the Peruvian Maceo and Ceara cottons, however, take a high position, both in the general perfection of the staple and the general regularity of the fibres, and are largely used either by themselves or along with high-class American in the production of yarns where the American staple is too short for the counts, when spun by itself, and Egyptian too dear in the white quality and too highly coloured in the lower-priced brown.

Brazilian cotton very closely resembles the white Egyptian, except that it possesses a more robust fibre, which reaches its maximum in the rough qualities. The general appearance of this cotton is given in Fig. 53.

4. *American cotton*, such as is grown in the fertile regions forming the south portion of the United States, is the typical cotton fibre, the "King Cotton" about which so much is said, and which forms at present by far the largest part of the world's cotton crop. Its general uniformity, the skill with which it is grown, gathered, and cleaned, with the exception of the almost exclusive use of the saw-gin, make it pre-eminently "the" cotton fibre.

The excellence of its spinning qualities, within the range of counts where by far the largest quantity of yarn

is required, and the abundance which is obtained make it the leading cotton of the world. It is subject to variations from year to year both in regularity of staple and strength of the fibres, but in a country which stretches from the New England States to the Gulf of Mexico, and from the stormy shores of the Atlantic Ocean westward to the foot of the Rocky Mountains, such a thing as a general failure of the crop has hardly ever been known. The rapid

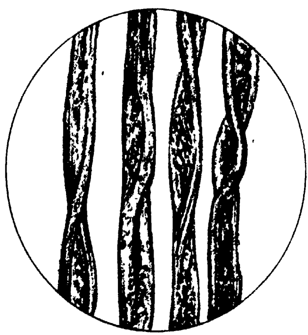

FIG. 53.—Fibres of Brazilian Cotton. × 200 diameters.

advance in population in the United States, however, renders it certain that a larger portion of this crop will be required year by year for home consumption, and emphasises the necessity for increasing the cotton-growing capacity of other parts of the world, and especially in British territory, so as to secure an abundant supply for the growing requirements of the United Kingdom.

When examined under the microscope, as compared with Egyptian cotton, its pure white colour and transparent character strike the eye at once, as do also the coarser nature of the fibre and its less general uniformity in

diameter. When examined in the yarn these characteristics give the thread a more loose and less solid character, as though the general structure of the fibres was more rigid and less yielding than Egyptian but more so than Brazilian, and in the fracture of the fibres the elasticity is less. Its usual soundness of staple and the freedom of the cellulose from both mechanical and chemical impurities render it eminently fitted for the production of all classes of yarn and goods where colour, regularity, and good wearing qualities are desirable. It is the cotton out of which the vast class of goods for domestic use are made, and it passes through the various processes necessary in its conversion from the raw state into the finished goods, whether plain or coloured, with less trouble and difficulty than any other kind. Its wearing character may be substantiated by the fact, that when made into the ropes used for the transmission of power in textile factories, it is found that those made from good American cotton wear better and last longer than those made from any other quality.

Fig. 54 gives a microscopical view of fibres of good American cotton where the general features of this class are clearly seen.

5. *Surat or East Indian cotton* stands last in the order of cottons. It possesses the shortest average staples, and is the coarsest in its nature, although there are some classes of Surat which have a comparatively fine staple, and reach their highest development in what are known as Berars and the Hingunghât of the Central Provinces. The fibres under the microscope present the appearance of well-marked twisted tubes, but they seem more frequently to be variable in the thickness of the tube walls and in the tendency to produce "kempy" fibres.

The shortness of the staple, and the large amount of fine sand and other mechanical impurities associated with this class of cotton render it relatively more wasteful than American in the process of spinning. The variability of the Indian climate, in regard to rainfall and drought, makes it as a rule less reliable in general character than American, but in favourable seasons either by itself, or mixed along with American, Surat possesses good spinning

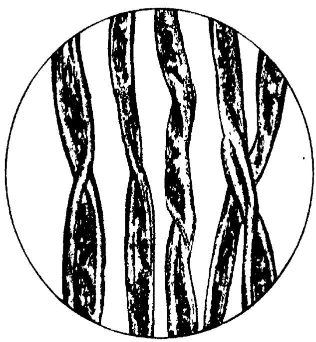

FIG. 54.—Fibres of American Cotton. × 130 diameters.

qualities and makes a full, solid, yet lofty thread, as might be expected from the robust character of the fibres. If properly attended to in the early stages of its growth and in the ginning and packing processes, there is no difficulty with suitable machinery in making first-class yarn and goods from it. Attempts are now being made to cultivate the Tree Cotton (*Gossypeum religiosum*) in India. This cotton is perennial. The tree is probably of Brazilian origin, where it is cultivated, and yields a coarse fibre used

for mixing with wool, but under cultivation it can be made to yield a staple suitable for spinning into both warp and weft. The tree is reported as very hardy, and when once planted continues to bear cotton for many years without attention, and stands both drought and frost. In India it is usually found in the precincts of the temples, and the cotton is used for making garments for the priests,

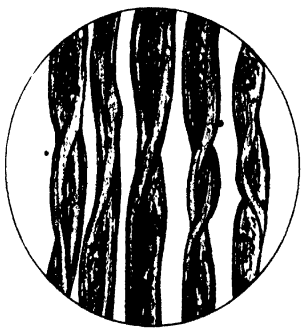

FIG. 55.—Fibres of Surat or Indian Cotton. × 170 diameters.

and wicks for the lamps used in the temples. Hence its name *religiosum*.

Fig. 55 gives a microscopical view of good Surat cotton and the robustness of the fibre; and the reason why it resists torsion, and as a consequence makes a full thread, is seen in the strength of the cell-walls and the relatively few number of twists.

There are a large number of different classes of cotton, each with distinctive features, and called either from the districts in which they are grown or from the ports from which they are exported, and each of these is found to be

specially adapted for making—either by itself or as a part of a mixing—special classes of yarn.

The following table gives the special names of the various classes of cotton ordinarily used for manufacturing processes, and for which prices are daily quoted in the Liverpool and Manchester Market. Appended to them in other columns are the species of cotton from which they are grown, the district where they are cultivated, and the average length of the longest staples, as well as the counts into which they are usually spun and for which they are specially adapted. These can only, however, be taken as generally correct, because within recent years non-indigenous cotton seed has been used in all countries, with a view to improve the staple or general quality of the fibre, and new varieties have been introduced, especially in the United States, as the result of cross fertilisation, which do not appear here; and also many new districts in all parts of the British Empire within the cotton zone are now, under the auspices of the British Cotton-Growing Association, growing cotton from different qualities of seed which are found best adapted to the locality, and these are not yet officially quoted.

The various qualities and varieties of cotton are arranged in this table in the order of the prices which they usually fetch, and this table may be profitably compared with the list issued daily by the Liverpool Cotton Brokers' Association.

The improvements in cultivation, the careful attention which in certain districts has been paid to the feeding of the soil with artificial manures, and the crossing of the native with foreign seed, so as to secure a plant which will thrive well in the climate and yet possess more valuable properties than the native cotton, have greatly

increased the value of many of these varieties and rendered it possible to spin them to higher counts than here given. The number might be increased, but those given may serve as a guide for the selection of cotton for any given purpose.

[TABLE

TABLE OF VARIOUS CLASSES OF COTTON.

Name.	District where grown	Species of Cotton.	Length of Staple in inches	Counts for which it is generally used.
SEA ISLAND				
Sea Island	Sea Islands on coast of Florida and Georgia	*Gossypeum Barbadense*	2·20 to 2·50	All the finest counts which are spun up to 200s.
Florida	Florida mainland	,, ,,	1·95 to 2·25	
Fiji, Tahiti	Polynesian Islands	,, ,,	1·88 to 2·00	
La Guayian	Venezuela	*Gossypeum hirsutum*	1·75	
Peruvian	Coast of Peru	*Gossypeum Peruvianum*	1·50	
Australian	Queensland	*Gossypeum Barbadense*	1·65 to 1·75	
EGYPTIAN				
Gallini Egyptian	Massetich, etc.	*Gossypeum Barbadense*	1·50 to 1·75	Up to 80s.
Brown ,,	Zagasig, Mansurah, Behara	*Gossypeum herbaceum*	1·40 to 1·50	Up to 140s.
White ,,	Ziftah, etc.	*Gossypeum hirsutum* and *Peruvianum*	1·25	Up to 80s.
Smyrna ,,	Levant and Greek Islands	*Gossypeum herboreum*	1·24	,,
BRAZILIAN				
Maranham	Coast of Brazil	*Gossypeum Peruvianum*	1·15	Alone and mixed with American and Egyptian cotton up to 60s.
Balua, Aracaju	San Salvador	,, ,,	1·25	
Pernam, etc.	Pernambuco	,, ,,	1·35	
Ceara, Aracata	North coast of Brazil	,, ,,	1·15	
Macio and Paraiba	Eastern coast of Brazil	,, ,,	1·20	
Rio Grand	South coast of Brazil	,, ,,	1·30	
West Indian	West Indian Islands	,, ,,	1·30	
Haytian	St. Domingo	,, ,,	1·30	
La Guayian	Venezuela	,, ,,	1·30	
Rough Peruvian	Peru	,, ,,	1·30	
Smooth ,,	Peru	,, ,,	1·35	

AMERICAN				
Upland cotton	Georgia and South Carolina	*Gossypeum hirsutum*	1·00	Alone up to 50^s, with white Egyptian and Brazilian up to 60^s.
Mobile ,,	Alabama and adjacent States	,, ,,	1·05	
Texas ,,	State of Texas	,, ,,	0·95	
Orleans ,,	Mississippi and Louisiana	,, ,,	1·10	
SURAT OR INDIAN				
Hingunghât cotton	Central Provinces	*Gossypeum herbaceum*	1·20	Alone up to 32^s, and mixed with American up to 40^s.
Dhawar ,,	Bombay	,, ,,	1·90	
Broach ,,	,,	,, ,,	0·90	
Dhollerah ,,	Bombay Feudatories	,, ,,	1·10	
Oomrawuttee ,,	Central Provinces	,, ,,	1·00	
Veravul ,,	,,	,, ,,	0·95	
Comptah ,,	,,	,, ,,	1·05	
Scinde ,,	Valley of Indus	,, ,,	1·00	
Bengal ,,	Bengal	,, ,,	1·10	
Rangoon ,,	British Burmah	,, ,,	0·85	
Madras:				
Tinnivelli ,,	Presidency of Madras	,, ,,	0·95	
Western ,,	,,	,, ,,	1·00	
AFRICAN				
Port Natal and many other parts of the continent	All parts of South Africa	*Gossypeum herbaceum*	1·25 0·90	Same as Surat.

CHAPTER XII

STRENGTH AND TESTING OF YARNS

THE strength and variation in the form of individual fibres, although of great scientific interest, has not the same industrial importance as the question of their united strength when they are associated together as fibres forming the structure of a thread, because single fibres are not used in any manufacturing process. The appearance of the fibres under the microscope has already been seen, and also the chemical composition of the fibre, and the variation which is introduced into the fibre by irregularity in the climatic conditions from year to year, and by those arising from the specific differences in the various species of cotton. It now remains to see

How far these Variations in the Ultimate Fibre may affect its Use in the Manufacturing Process, Mechanically and Chemically.

This is by far the most important part of the subject to technologists, because whatever knowledge may be gained in regard to the constitution and composition of the cotton fibre, the great object of the investigation must, from a practical view, be to see how far this knowledge will assist in throwing light upon the processes and manipulations which are daily used in the manufacturing process, and how

far it may assist in arranging these processes, so as to reach a higher standard of excellence in the manufactured goods or better modes of conducting them.

For this purpose the more that is known of the real structure and composition of the raw material the better, and also of the method of its action when brought into connection with chemicals and other reagents, because this knowledge will enable the manufacturer to guard against the imperfections, either in the yarn or goods, which arise from the variation in the mechanical or chemical structure of the raw material, and so either prevent or remedy the results arising from it.

It is well known how frequently apparently inexplicable imperfections are continually turning up in finished goods, and how difficult at times it is to decide the causes from which they arise, and those who have had to encounter these difficulties will at once appreciate the necessity for careful investigation of all possible causes, and the symptoms which they variously exhibit when examined under a closer vision and scrutiny than can usually be obtained with the ordinary means at the command of the manufacturer.

Conditions of Manufacture.—All changes through which raw material is passed, in its transference from the raw into the finished state, are either mechanical or chemical, or a combination of the two.

The strictly mechanical part of the process consists in the selection of the raw material and its preparation, so as to facilitate the arrangement of the separate filaments into something like regular and systematic order, so that the threads which are produced shall have a regular and even appearance, a uniform strength, and a certain weight in a given length.

If this is perfectly carried out, it will produce the same

characteristics in the woven goods, provided always that the process for changing the yarn into cloth is equally as perfect as the processes employed in spinning. The power to do this depends on:

1. The adaptation of the fibre to the use intended.
2. The degree of uniformity in the raw material.
3. The perfection of the machinery used.
4. The completeness and adaptability of the chemical processes to which the goods are subjected in dyeing and finishing.
5. The thoroughness and conscientiousness of the intelligent supervision.

Three of these conditions only come under the direct scope of this book, the first and last being outside the intention of the author, but it may be said, in regard to them, that no manufactured article will be successfully produced at a minimum cost when the raw material is not suited for the purpose, and however suitable the raw material may be, and however perfect all the mechanical processes, none of these advantages, either singly or collectively, will dispense with the intelligent and conscientious oversight of man.

The more raw material can be "mixed with brains" the higher will be the standard reached and the greater the chance of success in competition. Special emphasis must also be laid upon "conscientiousness," which may be defined as the unpurchasable heart-service which the true artist and workman throws into all his labour, and which, when it is present, is sure to make itself manifest in all his works and ways.

It has already been seen what degree of uniformity is presented in the cotton fibre, alike as regards length of staple, diameter and ripeness, and also that these variations

are sufficient to cause considerable difficulty in the attainment of perfection in the finished yarn and goods.

The general principles of spinning, which are employed in changing cotton into yarn, are now practically established for all time, and it appears that the method of drawing the fibres out between revolving rollers running at different speeds will always form the groundwork of continuous spinning. Improvements in machinery, which will increase production and render the action of the machines more sensitive and uniform, may from time to time be introduced, but, when the machinery is perfect, there will still remain the difficulty connected with the variation in the raw material.

It is not proposed to enter into the details of the mechanical processes, because not only would it occupy too much space, but it is outside the scope of this treatise, and for these particulars the reader is referred to Taggart's *Cotton Spinning*, which supplies three volumes to this technical series, where the spinning of cotton is fully explained, and to Fox's *Mechanism of Weaving*, also in the same series.

If the fibres were all perfectly uniform in length, the machinery for cleaning, carding, combing, drawing, roving, and spinning could be set to the exact adjustment which would be best fitted for the purpose, but with the variations which any lot of cotton presents all these arrangements are only a compromise, and as such cannot produce perfect work.

The nearest perfection is attained in combed yarns, where the fibres are mechanically selected by a machine in such a way as to attain a perfectly marvellous uniformity in length, and this secures a much greater degree of perfection in the uniformity of the yarn. Without combing

the only way to attain a high degree of perfection is to secure as perfectly uniform cotton as possible, and of a sufficiently high grade to enable it to be easily spun into the counts of yarn required.

Care should also be taken to see that, as may be judged by the strength of staple in the sample, the quantity of unripe fibres does not exceed a certain percentage, especially when the yarn is to be used for goods which have to be dyed in light shades, otherwise, as the unripe and immature fibres resist the action of the dyes and there are always some astringent and other unchanged cell-contents present in the fibres, these are sure to interfere with the dyeing and finishing process, and cause irregularity in their appearance.

Early arrivals of cotton are to be avoided, where great perfection is required, as they often contain a larger proportion of immature and unripe fibres than later deliveries, and also the fibres ripen in the bale, and may be used with impunity later on.

The nearer an approach is made to the limit of the spinning power of the cotton, that is to say, to the highest counts which can be spun out of it, the greater becomes the variation in the yarn. Hence yarn that is spun up, or produced from rovings designed for lower counts is always inferior to yarn which is spun down, or produced from rovings prepared for higher counts. The limit of regularity in spinning, even with the best machinery, seems to be reached when the section of the thread has less than ninety filaments of cotton in it, which seems to indicate that ordinary American cotton cannot be spun to counts much higher than 50's single, although with longer staple and combed yarns this limit of ninety filaments in the cross-section may be reduced down to about eighty.

Perfect Yarn.—In a perfect yarn the counts and the

twist would always be the same if the same length of yarn of the same counts was always taken, but in practice this never occurs, and every spinner knows that even in the best qualities of single and twofold yarns, when taken yard by yard for counts, and inch by inch for twist, there is a very great variation always found. It is only when the average is taken over a very wide range, that is to say, measure, and weight, and counts, over a considerable number of yards and inches, that anything like uniformity is reached in the average Taken yard by yard for counts, and inch by inch for twist, there is in all yarns a variation of above 20 per cent in both cases, while there is a wonderful average uniformity in both, if a hank is taken as the length from which to arrive at the counts, and a yard as the length from which to measure the number of turns of twist per inch.

This irregularity arises in large measure from imperfections in manufacture, as in the spinning it is usual to increase the number of times the sliver or roving is doubled together whenever first-class yarn is to be made, and in the mules the yarn in such cases is always spun from a double roving, as well as in the card-room.

The universal introduction, in all modern cotton mills, even where coarse counts are to be spun, of automatic weighing of the raw material in the opening and scutching machines, has undoubtedly led to a much greater regularity in the weight of the individual laps, and thus of the sliver from the carding engines, and the improvements in the cards also in regard to the feeding of the lap and uniformity in the width of the carding surface, have all tended in the same direction, but when all is done, there is always the difficulty, when the quantity of the raw material becomes reduced down to a small quantity as in the thread, arising

from the variation in the character of the separate fibres of which it is composed. The very improvements in machinery also tend, in practice, to emphasise this, because few spinners use a better raw material than is necessary to spin to the highest counts they require, and while, therefore, before the improvements in machinery were made, a given cotton, say American, could be spun to 40's, the same cotton can now be spun with equal ease up to 50's, but the raw material is not any better, and the same thread in 50's, while it may be as regular as the former thread in 40's, has not the same strength relatively, because the quality of the raw material, in regard to length of staple and other qualities upon which its strength depends, is only the same. However perfect the machinery, it still holds good that to make good yarn good raw material must be used. With a view to determine the degree of perfection to which the manufacture of cotton yarns has attained, the author made a large series of experiments with single twist and twofold yarns, in a large range of counts and qualities, the results of which are given in the tables following, and these were carefully verified by comparison with recent spinnings, and especially in regard to the strength of individual threads tested singly. These, when the first experiments were made, had to be done, thread by thread at a time, on a lever machine, the same as used in testing single fibres, only stronger and larger, and this proved a tedious process. Now, however, a machine has been invented which measures the length and records the breaking strain automatically upon a chart. By this means the whole of the single-thread tests were made, and may be compared with those made per lea given in the second set of tables. In the single-thread tests the length employed in testing was in each case 12 inches, and the twist was the standard twist.

In the second set of tables the length taken for determining the twist was 5 inches and 1 inch respectively, and for strength the length was 120 yards or 1 lea, which is the one-seventh part of the cotton hank.

The hank in cotton yarn measures 840 yards, and the number of hanks, per lb. weight, determine the number or counts of the yarn. The standard pound is the pound avoirdupois = 7000 grains. Thus if one pound of yarn contains $840 \times 20 = 16{,}800$ yards, it is said to be 20's, or $840 \times 40 = 33{,}600$ yards, it is 40's, and so on for any number either above or below.

Twofold yarns in cotton are called by the counts of the single yarn out of which the twofold yarn is made, and thus a hank of $\frac{2}{40}$ weighs the same as a hank of 20's single, and $\frac{2}{80}$ the same weight as 40's single. The silk hank is the same length as the cotton hank, and the counts are the same, but the worsted hank is only 560 yards, so that the cotton hank, which is 840, is 50 per cent longer. The counts differ in the same degree.

Metric Yarn Measures.—In France and other countries where the metric system of weights and measures is employed, the length and weight of the standard hank differs, because the metre is used as the standard of length, and is equal to 39·37079 inches, as against 36 inches in the yard, and the kilogramme is the standard of weight, and it is equal to 2·205 lbs. avoirdupois, and the gramme equal to 15·43 grains.

[TABLE

METRIC SYSTEM OF COUNTS

Counts.	Length in Metres	Weight in Grammes.
1s	1000 metres	500·000 grammes
2s	,,	250 000 ,,
3s	,,	166·66 ,,
4s	,,	125·00 ,,
5s	,,	100·00 ,,
6s	,,	83 33 ,,
7s	,,	71·43 ,,
8s	,,	62·50 ,,
9s	,,	55·55 ,,
10s	,,	50·00 ,,

The metric counts No. 1 is equal to 1·18 British hanks, and therefore it is only necessary to divide the British counts by 1·18 to give the metric counts, and multiply the metric counts by 1·18 to obtain the corresponding British counts.

It is very important in making experiments on the regularity in the counts of yarn to have a ready method of finding the weight in grains of a lea, or any number of leas, and this is easily determined.

One hank of cotton yarn is 840 yards and weighs 1 lb. which is 7000 grains, and therefore 1 lea, which is the seventh part of a hank, will weigh $\frac{7000}{7} = 1000$ grains, so that if W represents the weight in grains per lea, and C the counts of the yarn, then $W \times C = 1000$.

Therefore $$W = \frac{1000}{C},$$

and $$C = \frac{1000}{W}.$$

With these formulæ it is easy to calculate the weight from

the counts or the counts from the weight in grains of 1 lea or 120 yards.

The following table has been calculated in this way, and is given in one, two, three, and four leas, so that a better average may be obtained than when one lea only is used.

TABLE OF WEIGHTS OF VARIOUS COUNTS OF COTTON YARN

Counts.	Weight of one lea in grams.	Weight of two leas in grams.	Weight of three leas in grams.	Weight of four leas in grains.
1	1,000·000	2,000·000	3,000·000	4.000·000
2	500·000	1.006·000	1,500·000	2,000·000
3	333·333	666·666	1,000·000	1,333·333
4	250·000	500·000	750·000	1,000·000
5	200·000	400·000	600·000	800·000
6	166·666	333·333	499·999	666·666
7	142·857	285·714	428·571	571·428
8	125·000	250·000	375·000	500·000
9	111·111	222·222	333·333	444·444
10	100·000	200·000	300·000	400·000
11	90·909	181·818	272·727	363·636
12	83·333	166·666	250·000	333·333
13	76·923	153·846	230·769	307·692
14	71·428	142·857	214·285	285·714
15	66·666	133·333	199·999	266·666
16	62·500	125·000	187·500	250·000
17	58·823	117·647	176·470	235·294
18	55·555	111·111	166·666	222·222
19	52·631	105·263	157·894	210·526
20	50·000	100·000	150·000	200·000
21	47·619	95·238	142·857	190·476
22	45·454	90·909	136·363	181·818
23	43·478	86·956	130·434	173·913
24	41·666	83·333	124·999	166·666
25	40·000	80·000	120·000	160·000
26	38·461	76·923	115·384	153·846
27	37·037	74·074	111·111	148·148
28	35·714	71·428	107·142	142·857
29	34·482	68·965	103·447	137·931
30	33·333	66·666	99·999	133·333
31	32·258	64·516	96·774	129·032
32	31·250	62·500	93·750	125·000
33	30·303	60·606	90·909	121·212

TABLE OF WEIGHTS—*continued.*

Counts	Weight of one lea in grams.	Weight of two leas in grams.	Weight of three leas in grams.	Weight of four leas in grams.
34	29·411	58·823	88·234	117·647
35	28·571	57·142	85·713	114·285
36	27·777	55·555	83·332	111·111
37	27·027	54·054	81·081	108·108
38	26·363	52·727	79·090	105·263
39	25·641	51·282	76·923	102·564
40	25·000	50·000	75·000	100·000
41	24·390	48·780	73·170	97·560
42	23·809	47·619	71·429	95·238
43	23·255	46·511	69·766	93·023
44	22·727	45·454	68·181	90·909
45	22·222	44·444	66·666	88·888
46	21·739	43·478	65·217	86·956
47	21·276	42·553	63·829	85·106
48	20·833	41·666	62·499	83·333
49	20·408	40·816	61·224	81·632
50	20·000	40·000	60·000	80·000
51	19·607	39·215	58·822	78·431
52	19·230	38·461	57·691	76·923
53	18·867	37·735	56·602	75·471
54	18·518	37·037	55·555	74·074
55	18·181	36·363	54·544	72·727
56	17·857	35·714	53·571	71·428
57	17·543	35·087	52·630	70·175
58	17·241	34·482	51·723	68·965
59	16·949	33·898	50·817	67·796
60	16·666	33·333	49·999	66·666
61	16·393	32·786	49·179	65·573
62	16·129	32·258	48·387	64·516
63	15·873	31·746	47·619	63·492
64	15·625	31·250	46·875	62·500
65	15·384	30·769	46·153	61·538
66	15·151	30·303	45·454	60·606
67	14·975	29·850	44·825	59·701
68	14·705	29·411	44·116	58·823
69	14·492	28·985	43·477	57·971
70	14·285	28·571	42·856	57·142
71	14·084	28·169	42·253	56·338
72	13·888	27·777	41·665	55·555
73	13·698	27·397	41·095	54·794
74	13·513	27·027	40·540	54·054
75	13·333	26·666	39·999	53·333
76	13·181	26·363	39·544	52·727

TABLE OF WEIGHTS—*continued.*

Counts.	Weight of one lea in grains.	Weight of two leas in grains.	Weight of three leas in grains.	Weight of four leas in grains
77	12·987	25·974	38·961	51·948
78	12·820	25·641	38·461	51·282
79	12·658	25·316	37·971	50·632
80	12·500	25·000	37·500	50·000
81	12·345	24·691	37·036	49·382
82	12·195	24·390	36·585	48·780
83	12·048	24·096	36·144	48·192
84	11·904	23·809	35·713	47·619
85	11·764	23·529	35·293	47·058
86	11·627	23·255	34·882	46·511
87	11·494	22·988	34·482	45·977
88	11·363	22·727	34·090	45·454
89	11·235	22·471	33·706	44·943
90	11·111	22·222	33·333	44·444
91	10·989	21·978	32·967	43·956
92	10·869	21·739	32·608	43·478
93	10·752	21·505	32·257	43·010
94	10·638	21·276	31·914	42·553
95	10·526	21·052	31·578	42·105
96	10·416	20·833	31·249	41·666
97	10·309	20·618	30·927	41·237
98	10·204	20·408	30·612	40·816
99	10·101	20·202	30·303	40·404
100	10·000	20·000	30·000	40·000

If this table is required to be used for higher counts than 100's, it is best to double the number of leas, and then double the counts which the weight represents. Thus eight leas of 120's will weigh 66·666 grains, which corresponds to 60's on this table, and double this number is 120's, which is the counts required. For twofold yarns, two leas will correspond to four on this table, as, for example, two leas of $\frac{2}{40}$'s will weigh 100 grains, which is the weight of four leas of single 40's. In any case it is better to use eight leas in place of four leas, when the numbers are above 100's, because the difference in weight

between one count and the next is so small that they can only be distinguished by very careful weighing; whereas, by increasing the number of leas, we increase the difference, so as to make it more readily appreciable and less liable to be mistaken for any other counts.

In making the experiments to determine the irregularities in the counts and breaking strain of single yarns of various counts and qualities, the yarns were all spun with standard twists for the various counts, and were all warp twist. The strength in weft yarns would always be less than these, because the twist is always less, as in the weft softness and filling-up properties are more important than strength, as their being less hard and consolidated gives a greater fulness in appearance and a better feeling to the goods. The rule by which the standard twist for mule yarns, as universally accepted, is arrived at, is by multiplying the square root of the counts, for mule yarns, by 3·75 for warp and 3·25 for weft. This is found to be the exact twist, in American yarns, which will set without permitting the yarn to curl up and form snarls or kinks.

[TABLE

TABLE OF SQUARE ROOTS OF COUNTS AND STANDARD TWISTS PER INCH FOR VARIOUS COUNTS OF YARN

Counts.	Square Root of Counts.	Indian and American Cotton.			Egyptian Cotton.		
		Mule Twist.	Mule Weft.	Ring-Frame Twist.	Mule Twist.	Mule Weft.	Ring-Frame Twist.
1	1·000	3·75	3·25	4·00			.
2	1·414	5·30	4·60	5·65		.	.
3	1·732	6·49	5·62	6·92			..
4	2·000	7·50	6·50	8·00			
5	2·236	8·38	7·26	8·94			...
6	2·449	9·18	7·96	9·79			.
7	2·645	9·92	8·59	10·58			
8	2·828	10·60	9·19	11·31		.	
9	3·000	11·25	9·75	12·00	.		...
10	3·162	11·85	10·27	12·64	11·44	10·10	11·44
11	3·316	12·43	10·77	13·26	11·95	10·55	11·95
12	3·464	12·99	11·25	13·85	12·47	11·01	12·47
13	3·605	13·52	11·71	14·42	13·00	11·57	13·00
14	3·741	14·03	12·16	14·96	13·46	11·89	13·46
15	3·872	14·52	12·48	15·49	13·96	12·32	13·96
16	4·000	15·00	13·00	16·00	14·40	12·72	14·40
17	4·123	15·46	13·40	16·49	14·86	13·12	14·86
18	4·242	15·90	13·78	16·97	15·27	13·48	15·27
19	4·358	16 34	14·16	17·43	15·71	13·87	15·71
20	4·472	16·77	14·53	17·88	16·09	14·21	16·09
22	4·690	17·58	15·24	18·76	16·88	14·81	16·88
24	4·898	18·37	15·92	19·57	17·63	15·57	17·63
26	5·099	19·11	16·57	20·39	18·35	16·21	18·35
28	5·291	19·84	17·80	21·16	19·04	16·83	19·04
30	5·477	20·54	17·80	21·90	19·75	17·42	19·75
32	5·656	21·21	18·38	22·62	20·40	18 00	20·40
34	5·830	21·86	19·95	23·32	21·02	18·55	21·02
36	6·000	22·50	19·50	24·00	21·64	19·09	21·64
38	6·164	23·11	20·03	24·65	22·23	19·61	22·23
40	6·324	23·71	20·55	25·29	22·81	20·13	22·81
42	6·480	24·30	21·06	25·92	23·37	20·62	23·37
44	6·633	24·87	21·55	26·53	23·92	21·10	23·92
46	6·782	25·43	22·04	27·12	24·45	21·58	24·45
48	6·928	25·98	22·51	27·71	24·98	22·04	24·98
50	7·071	26·51	22·98	28·28	25·50	22·50	25·50

TABLE OF SQUARE ROOTS—*continued*

Counts.	Square Root of Counts.	Indian and American Cotton.			Egyptian Cotton		
		Mule Twist.	Mule Weft.	Ring-Frame Twist.	Mule Twist.	Mule Weft	Ring Frame Twist
52	7·211	...	...	...	26·00	22·94	26·00
54	7·348	...	...	...	26·50	23·38	26·50
56	7·483	...	...	...	26·98	23·81	26·98
58	7·615	...	...	...	27·46	24·43	27·46
60	7·745	...	...	...	27·93	24·54	27·93
62	7·874	...	...	...	28·39	25·05	28·39
64	8·000	...	...	...	28·85	25·45	28·85
66	8·124	...	...	...	29·29	25·87	29·29
68	8·246	...	...	...	29·73	26·23	29·73
70	8·366	...	...	...	30·17	26·62	30·17
72	8·485	...	...	...	30·60	27·00	30·60
74	8·602	...	...	...	31·02	27·37	31·02
76	8·717	...	...	...	31·44	27·74	31·44
78	8·831	...	...	...	31·85	28·10	31·85
80	8·944	...	...	...	32·25	28·47	32·25
82	9·055	...	...	...	32·65	28·81	32·65
84	9·165	...	...	...	33·05	29·16	33·05
86	9·273	...	...	...	33·44	29·50	33·44
88	9·380	...	...	...	33·83	29·84	33·83
90	9·486	...	...	...	34·21	30·18	34·21
92	9·591	...	...	...	34·59	30·52	34·59
94	9·695	...	...	...	34·96	30·85	34·96
96	9·797	...	...	...	35·33	31·17	35·33
98	9·890	...	...	...	35·70	31·50	35·70
100	10·000	...	...	...	36·06	31·83	36·06
102	10·099	...	...	...	36·41	32·14	36·41
104	10·198	...	...	...	36·77	32·46	36·77
106	10·295	...	...	...	37·12	32·76	37·12
108	10·392	...	...	...	37·47	33·07	37·47
110	10·488	...	...	...	37·81	33·32	37·81
112	10·583	...	...	...	38·16	33·68	38·16
114	10·677	...	...	...	38·50	33·98	38·50
116	10·770	...	...	...	38·83	34·28	38·83
118	10·862	...	...	...	39·17	34·57	39·17
120	10·954	...	...	...	39·50	34·86	39·50

It will be noticed on looking at the table that the twist put into the Egyptian yarns is always rather less than the same counts in Indian or American cotton. Also that in the Indian or American cotton the twist put into the ring-frame yarn is always greater than in the mule twist, while in the Egyptian yarns the twist is exactly the same both in the mule twist and ring-frame twist for the same counts.

When the author first made his experiments on the strength of the various counts of yarn with the view of determining a standard method of accomplishing this, it was almost impossible to use any method of testing single threads, in consequence of the great length of time necessary to do this, and the universal method employed was to test the strength per lea; and for this purpose, as will be seen hereafter, several efficient machines had been devised. It is evident, moreover, that in the actual process of manufacture into textile fabrics it is the single threads particularly which have to carry the strain, although they undoubtedly, as in the case of a warp, to a certain extent mutually assist each other, but the real value of the warp yarn, so far as the weaving is concerned, does not consist in the joint strength of the combined threads, but in the regularity in strength of each individual thread; like the weakest link in a chain, it is the true measure of the value and weavability of the yarn.

Automatic Single-Thread Tester.—A machine is now in the market, "Moscrop's patent Automatic 'Single-Thread' Tester,"[1] which enables single-thread tests to be made with absolute accuracy, and the results automatically recorded on a prepared sheet, which is adjusted to a correct position to receive it, so that a series of small punctures on

[1] Supplied by Messrs. Cook and Co., 18 Exchange St., Manchester.

a graduated scale printed on the sheet indicates the breaking strain. The machine is driven by power, so that the torque is perfectly steady. When the following tests were made it was driven by a small electro-motor. The machine, of which a good illustration is given in Fig. 56, is made to hold cops or bobbins, and records on the paper 160 consecutive tests from each cop, that is, 960 tests from the six cops, so that a very large average is obtained. The time occupied in this test is about twenty minutes. The machine tests, during each cycle of operations, a definite and constant length of yarn, which is automatically measured out during each reciprocation. The threads are held at the correct length by means of self-adjusting nips. The cycle of operations during one test may be described as follows:—

1. The inward run of the carriage, which carries the cops or bobbins, presenting six threads respectively to their individual nips.

2. Outward run of the carriage, allowing a definite length of yarn to be delivered, and the breaking of this yarn against springs of special temper and guaranteed accuracy.

3. Recording the strength of the threads individually during the inward run of the carriage.

4. Clearing the tested yarns away from the nips, so as not to foul the next operation.

Fig. 57 gives a record card or sheet taken on the machine, from which the results of testing six cops of 20's mule twist are seen, and the method in which it is recorded. The whole of the six records are in one long row on a card, and not one above another, as shown here. The exact size is 18 in. long by 2¾ in. wide, so that every mark is quite clear and distinct. The use of springs for testing yarn, as against

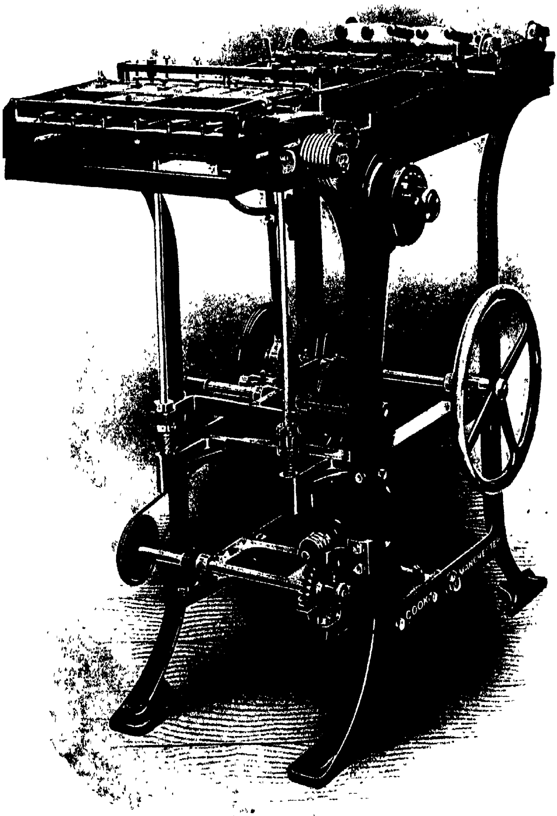

FIG. 56.—Single-Thread Testing Machine.

a fixed weight under the action of gravity, may be considered by some to be unreliable, but experience proves that in practice this is not the case. In the first place, the springs are made from a special quality of steel, carefully tempered, and tested in every way before being sent out. The full extent of the spring is never used, as it is so fixed in the machine that it can only be used to the extent of 50 per cent of its guaranteed elongation before straining. An arrangement is also provided by means of which the accuracy of the springs may at any time be verified by actual weights while the springs are in position in the machine; and, indeed, this is the method by which they are adjusted in the setting of the machine. This arrangement consists of a bar fixed across the machine, parallel to the front nips, to which the springs are attached. On the bar is a sliding pulley, revolving on pin points, so as to eliminate friction, and over this pulley, by means of a cord, is hung a weight holder for putting on the different weights which may be necessary to test the accuracy of the springs. If a weight of, say, 8 oz. or ½ lb. is hung in this way on to the front nips, the springs can be adjusted by means of set screws until the weight extends the springs, so that the needle point which records the strength is carried exactly to the position marked 8 oz. on the record paper. When once the springs have been correctly set, experience shows that there is little or no variation in them, so long as the adjusting screws are not altered, or the spring interfered with by accident or otherwise. They can also be tested at any time by the application of the weight again. A range of springs for testing any quality of yarn are supplied with each machine. The plate upon which the record paper is placed is so arranged, that when the standard sheet is placed in position the weights marked on the scale on the

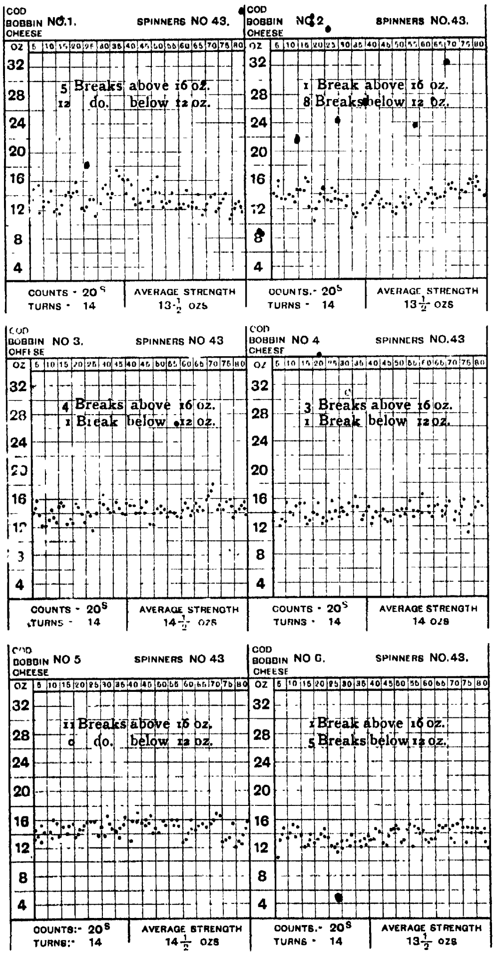

FIG. 57.—Moscrop's Recorder Test Sheet.

sheet always come into exact position to correspond with the weight to which the recording point is adjusted.

The following tables give the results of a series of tests on standard qualities of yarn in different counts, and generally in three qualities for each count, so as to give fairly accurate results of the range of cotton yarns, which are mostly used in manufacturing textile and other fabrics, and they give a good idea of the average strength of the threads and the variation which occurs in them. The yarns chosen were those which are largely in demand in the Lancashire, Yorkshire, and Nottingham trades, and also for export to the various manufacturing centres of the world. These yarns were supplied by Messrs. James Dilworth and Son, Manchester. The various tests made on single threads, as given below, may be compared with those made as usual by testing the yarn in a lea instead of by single threads, which will be given hereafter.

[TABLES

SAMPLE A

20's Single Twist. Good Quality. All American Cotton.

Average Counts, 20's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces	Max.	Min.	Aver.	Ounces	Max.	Min	Aver.	Ounces.	Max.	Min.	Aver.
1	12·00				11·75				12·25			
	12·50				12·00				12·50			
	11·25				12·25				9·50			
	11·00				13·00				13·00			
	11·75				13·50				12·00			
	12·50	12·50	11·00	11·83	11·50	13·50	11·50	12·33	11·75	13·00	9·50	11·83
2	12·25				11·25				10·75			
	12·00				11·50				12·25			
	10·75				12·25				12·00			
	10·50				11·00				12·00			
	13·00				11·75				11·25			
	13·50	13·50	10·50	12·00	13·25	13·25	11·00	11·81	9·50	12·25	9·50	11·30
3	13·00				10·75				12·00			
	13·00				11·00				12·25			
	11·25				11·00				12·00			
	10·75				12·00				10·75			
	10·75				12·25				11·00			
	11·25	13·00	10·75	11·66	11·00	12·25	10·75	11·33	11·00	12·25	10·75	11·50
4	13·00				10·50				11·75			
	13·00				10·75				12·00			
	13·50				11·25				13·00			
	12·00				11·50				10·50			
	11·25				11·75				11·00			
	11·00	13·50	11·00	12·31	12·50	12·50	10·50	11·36	10·50	13·00	10·50	11·46

The maximum average is 13·5 ounces. The lowest average is 9·5 ounces. The average of the averages is 11·72 ounces. The greatest variation is 4 ounces, which is nearly 33 per cent on the average strength.

SAMPLE B

24's Single Twist. Good Quality. All American Cotton.

Average Counts, 24's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	9·25				6·75				10·25			
	8·75				7·75				9·00			
	9·00				8·75				9·00			
	9·50				9·25				8·50			
	8·50				10·25				8·75			
	9·00	9·25	8·50	9·00	9·75	10·25	6·75	8·25	10·75	10·75	8·50	9·37
2	10·00				8·75				9·25			
	9·75				9·00				9·00			
	8·75				9·00				9·25			
	9·25				9·25				8·75			
	9·00				8·75				8·75			
	8·50	10·00	8·50	9·21	9·00	9·25	8·75	8·96	9·00	9·25	8·75	9·01
3	9·00				10·00				8·75			
	9·00				8·75				8·50			
	9·75				9·00				9·50			
	8·75				8·50				9·75			
	9·00				9·50				9·25			
	9·25	9·75	8·75	9·13	9·50	10·00	8·50	9·21	9·00	9·75	8·50	9·11
4	8·25				9·00				10·00			
	9·75				9·00				9·00			
	9·00				9·25				9·00			
	9·25				8·75				8·75			
	10·00				10·00				8·50			
	9·00	10·00	8·25	9·21	9·50	10·00	8·50	9·25	10·00	10·00	8·50	9·11

The maximum average is 10·75 ounces. The minimum average is 8·25 ounces. The average of the averages is 9·01 ounces. The greatest variation is 2·5 ounces, which is about 28 per cent on the average strength.

SAMPLE C

26's Single Twist. Good Quality. All American Cotton.

Average Counts, 26's.

Single Thread. Length tested, 12 inches.

Experiment	Strength in Ounces				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	8·25				7·25				8·25			
	7·50				7·75				8·00			
	7·75				8·00				7·75			
	8·00				7·50				7·75			
	8·50				8·25				8·25			
	7·25	8·50	7·25	7·70	8·50	8·50	7·50	7·87	7·75	8·25	7·75	7·79
2	7·75				7·00				8·00			
	8·25				7·25				8·25			
	8·00				7·75				7·25			
	8·25				8·50				8·50			
	8·50				8·25				8·25			
	7·75	8·50	7·75	8·01	8·75	8·75	7·00	7·91	8·50	8·50	7·25	8·12
3	8·25				7·75				8·25			
	8·00				8·50				7·75			
	8·50				8·25				7·00			
	8·00				7·50				8·50			
	7·25				8·50				8·50			
	8·00	8·25	7·25	8·00	8·50	8·50	7·50	8·17	7·75	8·50	7·00	7·95
4	8·25				7·25				7·25			
	8·50				8·25				8·00			
	8·25				8·25				8·75			
	8·00				7·50				7·25			
	7·50				8·50				8·00			
	8·25	8·50	7·50	8·10	8·00	8·50	7·25	7·94	8·25	8·75	7·25	7·75

The maximum average is 8·75 ounces. The minimum average is 7 ounces. The average of the averages is 7·86 ounces. The greatest variation is 1·75 ounces, which is about 23 per cent on the average strength

SAMPLE D'

32's Single Twist. Super Quality. All American Cotton.

Average Counts, 31·8's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	8·00				8·25				7·90			
	7·00				9·00				7·50			
	7·25				10·00				8·00			
	8·00				9·25				8·25			
	9·25				8·75				9·00			
	8·00	9·25	7·00	7·91	8·00	10·00	8·00	8·88	7·75	9·00	7·50	8·07
2	9·00				13·00				12·00			
	9·25				9·00				10·75			
	10·25				7·00				10·25			
	11·00				9·50				9·50			
	10·75				8·75				10·50			
	11·00	11·00	9·00	10·21	10·00	13·00	7·00	9·54	9·00	12·00	9·00	10·33
3	10·00				12·00				11·50			
	11·00				11·00				10·25			
	10·00				10·25				10·00			
	10·75				10·25				11·25			
	8·75				8·75				9·25			
	9·25	11·00	8·75	9·96	9·25	12·00	8·75	10·25	8·75	11·50	8·75	10·15
4	8·00				10·25				10·00			
	10·25				9·25				9·25			
	9·00				11·00				11·00			
	9·25				8·75				8·75			
	11·00				10·75				10·25			
	9·25	11·00	8·00	9·46	10·00	11·00	8·75	10·00	11·00	11·00	8·75	10·04

The maximum average is 13 ounces. The minimum average is 7 ounces. The average of the averages is 9·56 ounces. The greatest variation is 6 ounces, which is about 63 per cent on the average strength.

SAMPLE E

36's Single Twist. Good Quality. All American Cotton.

Average Counts, 36's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	8·00				7·25				8·00			
	7·25				7·00				6·25			
	6·75				8·25				7·25			
	8·25				6·25				7·50			
	9·25				7·00				6·75			
	6·25	9·25	6·25	7·61	8·00	8·25	6·25	7·30	7·00	8·00	6·25	7·13
2	7·00				6·75				7·00			
	7·00				8·75				7·25			
	8·00				6·00				8·25			
	6·75				7·00				8·00			
	6·50				7·12				7·75			
	7·00	8·00	6·50	7·01	6·50	8·75	6·50	7·02	7·00	8·25	7·00	7·54
3	8·25				7·00				8·25			
	8·75				7·25				8·00			
	9·00				7·75				8·00			
	7·25				8·00				10·00			
	6·75				9·00				7·25			
	6·25	9·00	6·25	7·71	6·75	9·00	6·75	7·62	7·00	10·00	7·00	8·08
4	7·75				8·25				7·25			
	8·25				7·15				7·00			
	7·00				7·25				8·00			
	6·75				8·25				8·25			
	9·00				6·75				7·25			
	8·75	8·75	6·75	7·91	7·25	8·25	6·75	7·41	7·00	8·25	7·00	7·46

The maximum average is 10 ounces. The minimum average is 6·25 ounces. The average of the averages is 7·49 ounces. The greatest variation is 3·75 ounces, which is about 51 per cent on the average strength.

SAMPLE F

40's Single Twist. Good Quality. All American Cotton.

Average Counts, 40's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min	Aver.	Ounces	Max	Min.	Aver	Ounces	Max	Min.	Aver.
1	6·25				7·25				6·00			
	7·00				6·25				6·25			
	6·25				6·75				6·75			
	7·75				5·75				5·75			
	7·00				5·75				7·25			
	6·00	7·75	6·00	6·71	7·00	7·25	5·75	6·16	7·00	7·25	5·75	6·50
2	6·25				7·25				5·50			
	7·00				6·00				6·50			
	5·50				6·00				5·75			
	6·00				5·25				5·25			
	6·25				5·50				7·00			
	5·25	7·00	5·25	6·04	7·00	7·25	5·25	6·11	7·25	7·25	5·25	6·21
3	5·75				7·00				6·00			
	6·00				6·00				5·50			
	7·00				5·25				5·25			
	5·25				5·00				4·75			
	4·75				7·50				6·00			
	5·75	7·00	4·75	5·75	4·75	7·50	4·75	5·95	5·75	6·00	5·25	5·54
4	7·25				6·25				5·75			
	7·00				6·00				7·00			
	6·25				5·75				6·25			
	6·00				5·25				6·00			
	5·50				7·25				5·75			
	5·75	7·25	5·50	6·30	7·00	7·25	5·25	6·40	7·25	7·25	5·75	6·33

The maximum average is 7·75 ounces. The minimum average is 4·75 ounces. The average of the averages is 6·20 ounces. The greatest variation is 3 ounces, which is about 48 per cent on the average strength.

SAMPLE G

40's Single Twist. Good Quality. All Egyptian Cotton.

Average Counts, 40's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	7·25				7·00				7·25			
	8·25				7·50				6·50			
	6·75				6·50				6·75			
	7·75				7·25				7·75			
	7·00				6·25				8·00			
	6·75	8·25	6·75	7·29	8·00	8·00	6·25	7·07	7·00	8·00	6·50	7·21
2	7·25				7·50				7·00			
	8·00				6·50				6·50			
	8·25				8·25				6·75			
	6·25				6·75				7·75			
	7·00				6·00				7·50			
	6·00	8·25	6·00	7·29	6·25	8·25	6·00	6·87	7·25	7·75	6·50	7·12
3	6·75				8·00				6·25			
	6·50				7·25				6·25			
	7·00				7·50				7·00			
	7·25				6·50				7·25			
	6·25				6·75				6·75			
	6·50	7·25	6·50	6·71	7·00	8·00	6·50	7·16	7·00	7·25	6·25	6·75
4	8·25				7·75				6·00			
	7·25				6·25				6·25			
	6·50				6·00				7·25			
	6·25				7·25				7·75			
	6·75				7·00				6·50			
	7·00	8·25	6·25	7·00	7·25	7·75	6·00	6·91	7·00	7·75	6·00	6·80

The maximum average is 8·25 ounces. The minimum average is 6 ounces. The average of the averages is 7·01 ounces. The greatest variation is 2·25 ounces, which is about 32 per cent on the average strength.

SAMPLE H

45's Single Twist. Good Quality. All American Cotton.

Average Counts, 45's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces				Strength in Ounces			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	4·25				5·00				4·75			
	5·00				4·75				3·75			
	6·25				4·50				4·00			
	4·75				5·25				5·25			
	3·90				4·75				5·75			
	3·75	6·25	3·75	4·65	5·00	5·25	4·50	4·88	4·25	5·75	3·75	4·62
2	5·25				6·25				5·50			
	5·00				6·00				5·75			
	6·25				6·25				6·50			
	5·75				5·75				4·75			
	6·00				4·75				7·25			
	6·25	6·25	5·00	5·75	4·50	6·25	4·50	5·58	5·00	7·25	4·75	5·80
3	4·75				6·25				5·50			
	4·50				6·00				5·00			
	4·25				5·00				4·25			
	6·75				4·50				4·75			
	6·25				4·25				6·00			
	4·75	6·75	4·25	5·21	6·75	6·75	4·25	5·46	5·25	6·00	4·25	5·12
4	4·50				5·00				6·00			
	4·75				5·00				5·00			
	6·00				4·75				5·00			
	5·00				5·25				4·25			
	4·25				4·75				4·25			
	4·50	6·00	4·25	4·83	4·50	5·25	4·50	4·87	4·75	6·00	4·25	5·04

The maximum average is 7·27 ounces. The minimum average is 3·75 ounces. The average of the averages is 4·70 ounces. The greatest variation is 3·42 ounces, which is about 72 per cent on the average strength.

SAMPLE I

45's Single Twist. Good Quality. All Egyptian Cotton.

Average Counts, 45's.

Single Thread. Length tested, 12 inches.

Experiment	Strength in Ounces				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces	Max.	Min.	Aver.	Ounces	Max.	Min	Aver.
1	6·00				7·25				6·25			
	7·75				6·00				5 00			
	7·00				6·25				7·00			
	6·25				5·75				6·25			
	6·25				5·50				5·75			
	7·75	7·75	6·00	6·82	6·00	7·25	5·50	6·12	6·00	7·00	5·00	6·04
2	5·50				5·25				6·00			
	5 75				4·75				5·25			
	6·25				5·75				5·00			
	5·00				5·00				4·50			
	5·00				6·25				6·25			
	7·00	7·00	5·00	5·71	4·75	6·25	4·75	5·27	5·25	6·25	4·5	5·37
3	4·75				5·00				4·75			
	4·50				4·50				4·75			
	5·00				5·25				4·25			
	5·25				4·25				5·25			
	4·25				5·00				4·75			
	4·50	5·25	4·50	4·71	4·75	5·25	4·25	4·79	4·50	5·25	4·25	4·63
4	5·25				6·00				6·25			
	5·25				5·75				6·00			
	4·75				4·25				4·75			
	4·25				4·75				4·25			
	4·75				5·00				4·75			
	5·00	5·25	4·25	4·87	6·00	6·00	4·25	5·30	5·25	6·25	4·25	5·21

The maximum average is 7·75 ounces. The minimum average is 4·25 ounces. The average of the averages is 5·40 ounces. The greatest variation is 3·5 ounces, or about 65 per cent on the average strength.

SAMPLE J

50's Single Twist. Good Quality. All Egyptian Cotton.

Average Counts, 50's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	5·00				4·75				5·25			
	6·25				5·25				6·00			
	4·75				5·00				4·50			
	4·50				5·00				5·75			
	6·25				5·25				5·00			
	6·00	6·25	4·50	5·16	4·50	5·25	4·50	4·77	4·25	6·00	4·25	5·12
2	4·25				5·00				5·25			
	3·75				4·25				4·00			
	4·50				5·00				4·50			
	5·00				5·75				5·00			
	5·25				4·00				4·75			
	4·75	5·25	3·75	4·60	4·75	5·75	4·00	4·79	3·75	5·25	3·75	4·54
3	5·00				3·75				5·00			
	5·25				5·25				4·75			
	4·75				5·00				4·25			
	5·00				5·50				5·50			
	5·00				4·25				6·00			
	4·75	5·25	4·75	4·96	4·75	5·50	3·75	4·75	4·75	6·00	4·25	5·03
4	6·00				4·50				5·00			
	5·75				4·75				5·00			
	5·25				5·25				4·00			
	5·50				5·00				5·75			
	4·75				4·25				4·75			
	4·50	6·00	4·50	5·30	6·00	6·00	4·25	4·96	4·25	5·75	4·00	4·79

The maximum average is 6·25 ounces. The minimum average is 3·75 ounces. The average of the averages is 5 ounces. The greatest variation is 2·5 ounces, which is exactly 50 per cent of the average strength.

SAMPLE K

60's Single Twist. Super Quality. All Egyptian Cotton.

Average Counts, 60's.

Single Thread. Length tested, 12 inches.

Experiment	Strength in Ounces				Strength in Ounces.				Strength in Ounces.			
	Ounces	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	5·00				3·75				5·00			
	4·75				4·50				4·75			
	4·50				5·00				4·50			
	4·25				5·50				3·75			
	3·75				5·25				5·00			
	5·25	5·25	3·75	4·60	4·75	5·50	3·75	4·79	3·50	5·00	3·50	4·43
2	5·50				3·75				5·25			
	4·25				3·50				4·25			
	4·50				4·75				3·75			
	4·50				4·50				5·00			
	3·50				5·75				5·50			
	5·75	5·75	3·50	4·66	4·50	5·75	3·50	4·37	3·50	5·50	3·50	4·54
3	5·25				5·25				3·75			
	6·00				5·00				3·25			
	5·00				4·50				5·00			
	4·25				4·25				4·50			
	3·25				3·50				4·75			
	3·75	6·00	3·25	4·58	4·50	5·25	3·50	4·66	3·75	5·00	3·25	4·17
4	5·25				3·50				5·25			
	4·75				4·00				4·25			
	3·25				4·50				3·75			
	4·50				5·25				3·50			
	4·50				5·00				4·75			
	4·50	4·75	3·25	4·54	4·25	5·25	3·50	4·41	4·25	5·25	3·50	4·30

The maximum average is 4·79 ounces. The minimum average is 3·25 ounces. The average of the averages is 4·52 ounces. The greatest variation is 1·54 ounces, which is 33 per cent on the average strength.

SAMPLE L

70's Single Twist. Super Quality. All Egyptian Cotton.

Average Counts, 60·5's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	4·25				3·75				4·00			
	3·75				3·25				4·25			
	4·00				4·50				3·75			
	3·50				4·00				3·50			
	4·25				4·25				4·75			
	3·75	4·25	3·50	3·91	3·50	4·50	3·25	3·87	4·25	4·75	3·50	4·10
2	4·25				3·25				4·00			
	3·00				3·00				4·00			
	3·75				3·75				3·25			
	3·25				3·00				3·00			
	4·00				3·75				3·75			
	3·25	4·25	3·00	3·58	3·75	3·75	3·00	3·10	4·00	4·00	3·00	3·66
3	4·00				3·75				4·00			
	4·25				3·25				4·00			
	3·75				4·00				4·25			
	4·75				4·00				3·00			
	3·50				3·25				3·25			
	5·00	5·00	3·50	4·21	3·75	4·00	3·25	3·66	3·75	4·25	3·00	3·71
4	5·00				3·75				3·25			
	4·00				4·00				3·00			
	3·50				4·00				3·00			
	3·75				3·25				4·00			
	5·00				3·25				4·25			
	3·25	5·00	3·25	4·08	4·50	4·50	3·25	3·81	3·25	4·25	3·00	3·62

The maximum average is 5 ounces. The minimum average is 3 ounces. The average of the averages is 3·8 ounces. The greatest variation is 2 ounces, which is about 53 per cent on the average strength.

SAMPLE M

80's Single Twist. Super Quality. All Egyptian Cotton.

Average Counts, 80's.

Single Thread. Length tested, 12 inches.

Experiment	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	3·25				3·00				3·25			
	2·75				3·50				3·00			
	3·00				3·00				2·75			
	3·00				3·75				2·50			
	2·25				2·75				3·50			
	2·50	3·25	2·50	2·80	2·50	3·75	2·50	3·08	3·00	3·50	2·50	3·00
2	2·25				3·00				2·75			
	2·75				3·00				2·50			
	3·50				2·25				3·25			
	3·25				2·75				3·00			
	2·75				3·25				2·75			
	3·00	3·50	2·25	2·91	2·75	3·25	2·25	2·83	3·25	3·25	2·50	2·90
3	2·75				3·50				2·75			
	3·25				2·50				2·25			
	2·50				2·75				2·25			
	2·75				2·25				3·25			
	2·00				3·75				3·00			
	3·00	3·75	2·00	2·70	3·25	3·75	2·25	3·00	2·50	3·25	2·25	2·66
4	3·00				2·75				3·00			
	3·25				2·50				2·00			
	3·50				2·75				2·75			
	2·75				3·50				3·25			
	2·50				3·50				2·50			
	3·25	3·50	2·50	3·04	3·25	3·50	2·50	3·04	2·75	3·25	2·50	2·71

The maximum average is 3·75 ounces. The minimum average is 2 ounces. The average of the averages is 2·9 ounces. The greatest variation is 1·75 ounces, which is 60 per cent on the average strength.

It will be noticed that the single yarns are only tested thread by thread up to 80's single, as within this range is included by far the largest number of counts which are used in single yarns, and these were all taken promiscuously from well-known spinnings, and may be taken as typical of their class. The general results of all the tests may be summarised in the following table:—

TABLE OF STRENGTH AND VARIATION IN SINGLE YARNS, TESTED SINGLE THREADS AT A TIME

Mark.	Counts.	Cotton.	Quality.	Maximum strength in Ounces.	Minimum strength in Ounces.	Average strength in Ounces.	Greatest variation in Ounces.	Variation per cent.
A	20s	All American	Good	13·50	9·50	11·72	4·00	33
B	24s	,,	,,	10·75	8·25	9·01	2·50	28
C	26s	,,	,,	8·75	7·00	7·86	1·75	23
D	32s	,,	Super	13·00	7·00	9·56	6·00	63
E	36s	,,	Good	10·00	6·25	7·49	3·75	51
F	40s	,,	,,	7·75	4·75	6·20	3·00	48
G	40s	All Egyptian	,,	8·25	6·00	7·01	2·25	32
H	45s	All American	,,	7·27	3·75	4·70	3·42	72
I	45s	All Egyptian	,,	7·75	4·25	5·40	3·50	65
J	50s	,,	,,	6·25	3·75	5·00	2·50	50
K	60s	,,	Super	4·79	3·25	4·52	1·54	33
L	70s	,,	,,	5·00	3·00	3·80	2 00	53
M	80s	,,	,,	3·75	2·00	2·90	1·75	60

Although it is not wise to draw general conclusions from too limited a number of experiments, still, the experience of the author in the testing of yarns enables him to know that these tests give a fair average of what may be expected from these class of yarns.

In looking at the results of the testings in A, B, and C samples, it will be noticed that the greatest regularity is in C, which is spun down from 32's quality. The 20's and 24's are spun from 24's quality. The 32's D sample is spun

from rovings and cotton prepared for 32's, and the quality of cotton will not be better than that which will make the yarn commercially satisfactory. A glance at the Table D giving the individual tests will show that although the counts are on the light side on the average, still some of the threads must have been on the coarse side. E, the 36's, was spun down from F, the 40's roving. The difference between F and G in regularity must be specially noticed, because it shows how the same counts, 40's single, made from Egyptian cotton are superior in regularity to the American yarn; the former having a longer staple and a finer fibre, and consequently a larger number of fibres in the cross-section of the thread, both of which give advantage in every way. Sample K, the 60's super, was spun down from the same rovings as used for the 80's in sample M. The sample L, 70's, was also spun down from M rovings. The highest variation in strength per cent was in the 1/45's American, and the lowest in the 1/26's American, and the average of the whole was 47 per cent. The average variation in the all American yarns was 47 per cent, and in the all Egyptian yarns 49 per cent.

The author also made a number of experiments with these single yarns to endeavour to determine the degree of regularity in the elasticity of the yarn, but found in all cases the variation in individual threads was too great to base any general average upon. All the counts seemed at first to take a permanent set whenever any tension was put upon them, which arises from the fibres drawing out by sliding out over each other until they get a firm grip of each other; then they display a certain degree of elasticity and take no further set until the limit of the stretching power is reached, and then another set is taken, and the fibres either draw out or lose their hold, or the strain coming

on to them unequally, one fibre gives way, and the others follow seriatim, and the fracture of the thread occurs.

A series of tests were also made with twofold yarns, taken, as in the case of the single yarns, a single thread at a time, and each thread taken 12 inches in length, and each thread tested eighteen times. The results of these tests are embodied in the following tables.

[TABLE

SAMPLE A

Twofold 40's. Common Quality. All American Cotton.
Average Counts, 39·5's.
Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	14·00				13·25				14·00			
	12·25				14·00				15·00			
	14·75				14·00				15·25			
	14·25				12·75				13·75			
	13·50				12·75				14·00			
	13·25	14·00	13·25	13·66	13·75	14·00	12·75	13·41	14·00	15·25	13·75	14·33
2	13·75				15·00				14·00			
	14·25				15·25				14·00			
	14·00				14·00				13·25			
	13·75				13·75				15·00			
	12·75				14·25				14·25			
	14·00	14·25	12·75	13·75	14·00	15·25	13·75	14·37	14·00	15·00	13·25	14·09
3	15·00				13·25				14·25			
	14·75				13·75				13·50			
	13·25				14·25				13·75			
	13·75				14·50				14·50			
	14·00				14·75				14·75			
	14·25	15·00	13·25	14·17	13·75	14·75	13·25	14·01	13·50	14·75	13·50	14·01
4	13·50				14·00				14·00			
	13·75				14·25				13·25			
	13·25				14·25				14·25			
	14·25				13·75				14·50			
	14 75				13·50				14·75			
	15·00	15·00	13·25	14·12	14·25	14·25	13·50	14·00	12·75	14·75	12·75	13·91

The maximum average is 15·25 ounces. The minimum average is 12·75 ounces. The average of the averages is 14 ounces. The greatest variation is 2·5 ounces, which is about 18 per cent on the average strength.

SAMPLE B

Twofold 38's. Super Quality. All Egyptian Cotton.

Average Counts, 38·2's.

Single Thread. Length tested, 12¼ inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	19·25				20·25				18·75			
	20·50				20·30				20·00			
	20·30				20·50				21·00			
	20·25				20·00				21·50			
	20·00				19·75				20·50			
	19 50	20·50	19·25	19·96	20·00	20·5	19·75	20·13	21·00	21·50	18·75	20·46
2	19·75				17·50				23·00			
	20·50				18·90				21·98			
	21·00				21·50				20·75			
	21·25				21·75				20·25			
	20·30				20·30				22·00			
	20·75	21·25	19·75	20·01	21·50	21·75	17·50	20·26	20 75	23·00	20·25	21·45
3	20·30				19·75				21·30			
	21·00				19·75				22·40			
	22·00				20·25				23·80			
	21·50				20·50				21·00			
	20·25				21·00				22·80			
	24·00	24·00	20·30	21·51	20·75	20·75	19·75	20·33	24·00	24·00	21·30	23·05
4	22·50				24·00				20·50			
	23·00				23·80				20·75			
	23·50				24·00				21·25			
	24·00				24·20				21·75			
	24·00				21·30				22·00			
	22·30	24·00	22·30	23·21	22·00	24·20	21·30	23·21	21·50	22·00	20·50	21·46

The maximum average is 24 ounces. The minimum average 17·5 ounces. The average of the averages is 21·25 ounces. The greatest variation is 6·5 ounces, which is about 31 per cent of the average strength.

SAMPLE C

Twofold 40's. Super Quality. All Egyptian Cotton.

Average Counts, 40's.

Single Thread. Length tested, 12 inches.

Experiment	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	16·00				20·25				22·00			
	20·00				21·00				21·00			
	20·50				21·25				21·25			
	21·00				20·00				21·00			
	18·00				19·75				20·25			
	20·25	21·00	16·00	19·30	20·00	21·25	19·75	20·37	20·00	22·00	20·00	20·91
2	21·00				22·00				22·25			
	19·75				22·50				20·00			
	20·00				21·00				21·00			
	20·00				21·25				19·50			
	21·00				20·75				19·75			
	19·50	21·00	19·75	20·21	20·00	22·50	20·00	21·25	20·25	22·25	19·50	20·46
3	23·00				22·50				22·00			
	22·00				22·00				24·00			
	21·00				22·25				22·75			
	22·25				23·00				21·50			
	20·75				21·50				22·75			
	20·00	23·00	20·00	21·50	21·75	23·00	21·50	22·16	20·50	24·00	20·50	22·25
4	22·50				24·00				23·00			
	21·75				23·75				22·00			
	22·50				22·00				20·75			
	21·00				20·25				21·00			
	20·00				21·00				19·75			
	22·50	22·50	20·00	21·71	22·00	24·00	20·25	22·16	22·00	23·00	20·75	21·24

The maximum average is 24 ounces. The minimum average is 16 ounces. The average of the averages is 21·14 ounces. The greatest variation is 8 ounces, which is about 37 per cent on the average strength.

SAMPLE D

Twofold 50's. Super Quality. All Egyptian Cotton.

Average Counts, 50's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	17·00				12·00				18·00			
	17·25				14·00				17·25			
	16·50				14·25				18·00			
	16·00				13·25				17·00			
	17·00				13·00				16·75			
	17·25	17·25	16·00	16·83	14·00	14·25	12·00	13·41	18·00	18·00	16·75	17·50
2	16·25				16·00				15·75			
	16·00				16·25				15·25			
	15·25				15·00				16·00			
	14·75				15·50				16·50			
	16·25				16·00				17·00			
	16·00	16·25	14·75	16·58	16·25	16·25	15·00	15·83	16·50	17·00	15·25	16·16
3	16·75				17·00				16·75			
	17·00				18·00				16·50			
	16·25				17·25				17·00			
	12·25				16·75				17·00			
	17·00				16·25				17·50			
	17·00	17·00	12·25	16·04	17·00	18·00	16·75	17·04	16·25	17·50	16·25	16·75
4	16·25				17·25				17·25			
	18·00				17·00				17·00			
	17·00				16·25				17·00			
	17·00				18·00				16·75			
	17·25				15·75				17·00			
	17·00	18·00	16·25	17·08	17·00	18·00	15·75	16·87	17·25	17·25	16·75	17·04

The maximum average is 18 ounces. The minimum average is 12 ounces. The average of the averages is 16·43 ounces. The greatest variation is 6 ounces, which is a little over 38 per cent on the average strength.

SAMPLE E

Twofold 60's. Super Quality. All Egyptian Cotton.

Average Counts, 60·25's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.	Ounces.	Max.	Min.	Aver.
1	14·00				15·00				13·00			
	14·75				15·75				13·50			
	12·25				16·00				15·00			
	15·50				15·25				14·75			
	14·75				15·00				15·00			
	16·00	16·00	12·25	14·54	15·75	16·00	15·00	15·16	14·25	15·00	13·00	14·25
2	16·00				14·00				15·00			
	15·75				14·25				14·25			
	15·00				13·75				14·75			
	14·25				15·00				13·50			
	13·50				14·00				13·50			
	13·25	16·00	13·50	14·61	13·75	15·00	13·75	14·12	14·75	15·00	13·50	14·29
3	16·00				15·00				14·25			
	15·00				14·75				14·00			
	14·75				14·25				14·00			
	13·25				13·75				13·75			
	13·75				15·00				14·25			
	14·00	16·00	13·25	14·46	14·25	15·00	14·25	14·50	13·25	14·25	13·25	13·91
4	13·75				14·00				14·25			
	13·00				13·00				14·00			
	13·50				13·50				13·75			
	14·00				15·00				13·50			
	14·25				14·75				14·75			
	13·50	14·25	13·00	13·66	13·25	15·00	13·00	13·91	14·00	14·75	13·50	14·04

The maximum average is 16 ounces. The minimum average is 12·25 ounces. The average of the averages is 14·23 ounces. The greatest variation is 4·75 ounces, which is 33 per cent on the average strength.

SAMPLE F

Twofold 70's. Super Quality. All Egyptian Cotton.

Average Counts, 70's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces	Max.	Min.	Aver.	Ounces.	Max.	Min	Aver.	Ounces.	Max.	Min.	Aver.
1	12·00				12·25				13·00			
	12·25				12·00				12·25			
	11·25				12·00				11·50			
	11·75				11·75				12·25			
	12·00				10·25				12·00			
	12·00	12·25	11·25	11·88	12·75	12·75	10·25	11·83	12·00	13·00	11·50	12·17
2	12·00				12·25				11·25			
	12·25				12·25				10·75			
	12·25				12·00				12·25			
	11·75				11·75				12·25			
	11·50				11·25				12·00			
	12·00	12·25	11·50	11·96	12·00	12·25	11·25	11·91	12·00	12·25	10·75	11·75
3	12·25				12·25				13·50			
	11·00				12·00				12·25			
	11·00				12·00				13·50			
	12·00				14·00				13·50			
	11·75				13·75				12·50			
	12·75	12·75	11·00	11·80	12·75	13·75	12·00	12·80	12·00	13·50	12·00	12·87
4	14·25				12·25				12·25			
	14·00				12·75				13·00			
	14·00				13·25				12·00			
	13·50				12·00				11·75			
	13·00				12 75				12·25			
	12·50	14·25	12·50	13·54	12·50	13·25	12·00	13·60	11·50	13·00	11·50	12·12

The maximum average is 14·25 ounces. The minimum average is 10·25 ounces. The average of the averages is 12·27 ounces. The greatest variation is 4 ounces, which is 32 per cent on the average strength.

SAMPLE G

Twofold 80's. Super Quality. All Egyptian Cotton.

Average Counts, 80's.

Single Thread. Length tested, 12 inches.

Experiment.	Strength in Ounces.				Strength in Ounces.				Strength in Ounces.			
	Ounces.	Max.	Min.	Aver.	Ounces	Max.	Min.	Aver.	Ounces	Max.	Min.	Aver.
1	10·25				10·00				9·25			
	9·75				11·00				9·75			
	9·75				10·75				8·75			
	10·00				9·25				10·00			
	10·25				9·50				9·75			
	10·00	10·25	9·75	9·94	10·25	11·00	9·25	9·94	10·25	10·25	9·25	9·16
2	10·00				9·00				10·00			
	10·25				9·25				10·25			
	9·75				9·50				9·25			
	9·75				9·25				9·00			
	9·50				9·00				9·00			
	10·25	10·25	9·50	9·61	9·50	9·50	9·00	9·08	8·75	10·25	8·75	9·37
3	10·25				8·75				10·00			
	9·25				8·75				9·25			
	9·25				9·25				9·75			
	9·75				9·75				8·75			
	9·00				10·00				8·75			
	10·00	10·25	9·00	9·88	9·00	10·00	8·75	9·25	10·25	10·25	8·75	9·16
4	9·25				10·00				10·00			
	9·00				10·25				10·00			
	9·00				9·50				9·75			
	8·75				9·25				9·25			
	9·75				9·00				10·25			
	9·25	9·75	8·75	9·16	9·00	10·25	9·00	9·50	10·00	10·25	9·25	9·87

The maximum average is 11 ounces. The minimum average is 8·75 ounces. The average of the averages is 9·54 ounces. The greatest variation is 2·25 ounces, which is about 23 per cent on the average strength.

In the same way as with the single-twist tests, the tests as above on the twofold yarns may be summarised in the following table:—

TABLE OF STRENGTH AND VARIATION IN TWOFOLD YARNS, TESTED SINGLE THREADS AT A TIME

Mark.	Counts.	Cotton	Quality.	Maximum strength in Ounces.	Minimum strength in Ounces.	Average strength in Ounces.	Greatest variation in Ounces.	Variation per cent.
A	2/40s	All American	Common	15·25	12·75	14·00	2·50	18
B	2/38s	All Egyptian	Super	24·00	17·50	21·25	6·50	31
C	2/40s	,,	,,	24·00	16·00	21·14	8·00	37
D	2/50s	,,	,,	18·00	12·00	16·43	6·00	38
E	2/60s	,,	,,	16·00	12·25	14·23	4·75	33
F	2/70s	,,	,,	14·25	10·25	12·27	4·00	32
G	2/80s	,,	,,	11·00	8·75	9·54	2·25	23

These figures call for no comment except to point out that all the Egyptian yarns were spun from the same quality of cotton and from the 2/80's rovings down as far as the 2/60's. The same cotton but a slightly heavier roving was used for the 2/50's, and the same spun down to the 2/40's and 2/38's.

The highest average variation in strength per cent was in the 2/50's Egyptian by 38 per cent, and the lowest variation was 18 per cent in the 2/40's American. The average variation was a little over 30 per cent. The average variation in the Egyptian yarns was 32·3 per cent. If these variations are compared with the variations in the strength of the single yarns, it will be seen that twofold yarns have a better average strength in the American yarns of 29 per cent and the Egyptian yarns of 16·7 per cent.

In making experiments with yarn in the lea, the cotton was wound off the cop or bobbin on to a reel 1½ yards

(54 inches) in diameter, which is the standard size of reel, so that each lea contained eighty threads. These threads were laid side by side on to the reel over a space of 1 inch by a self-acting motion, so as to prevent unequal tension in the threads, and a uniform tension put on to them in their passage from the cop or bobbin to the reel.

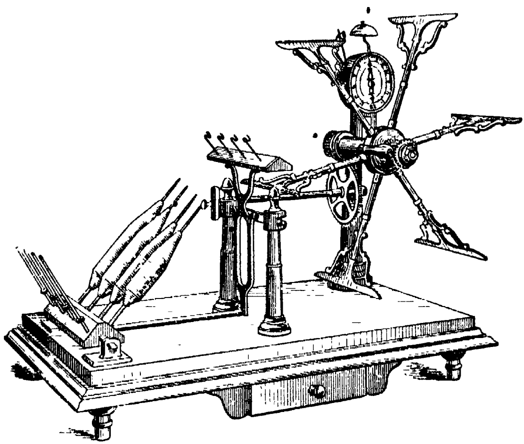

FIG. 58.—Wrap Reel for Cops or Bobbins.

A general idea of the form of this wrap reel, as it is called, will be obtained by looking at Fig. 58, which gives a good illustration of the form of this machine. The cops or bobbins are placed upon pegs or skewers, and the ends or threads conducted by suitable guides on to the swift of the reel. A slow motion is given to the guides as the swift revolves, which lays the threads practically parallel and side by side with a uniform tension.

A very ingenious form of sun-and-planet wheel enables

each revolution of the driving handle to revolve the swift twice, so that only forty revolutions of the driving handle are necessary to lay on the eighty threads. A dial driven by a worm-wheel measures the length, so as to prevent the necessity of counting the number of revolutions of the swift, and whenever 120 yards or one lea has been wound on, a bell rings to call attention.

Yarn Strength-Testing Machine.—The machine used for testing the strength of the yarn was of the ordinary form used in Lancashire for that purpose, which consists of two square hooks, one of which can be separated from the other vertically by the motion of a screw. This screw, in making the experiments, was actuated by power obtained from the shaft driven from the large engines at the extensive cotton mills in which the author was a partner, and which was perfectly uniform and steady. The motion of a small lever enabled the screw to be turned in either direction at pleasure. The upper hook is connected by a chain round the cylinder with a lever having a uniform weight fixed upon it, the angular deviation of which, from the vertical line, puts a strain upon the lea of yarn stretched between the two hooks, while a finger or pointer on the axis on which the cylinder revolves measures the angular deviation of the weight upon a graduated dial, and thus records the strain in pounds at which the lea of yarn breaks. A catch working at the end of the weight lever in a semicircular rack prevents the weight from falling when the lea of yarn breaks and this catch requires releasing, and the weight and pointer resetting after each testing is complete. The record weight in pounds was, in all cases, that at which the pointer stood when fracture was complete. Fig. 59 represents the testing-machine, from which the general

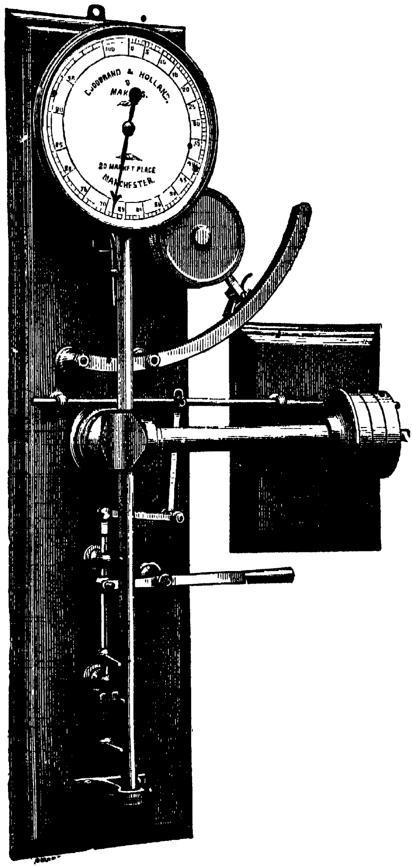

FIG. 59.—Lever Yarn-Testing Machine. Power-driven.

features of its construction, as given above, are clearly seen, and the method of driving by power from the main shaft is also quite clear. To have the testing-machine driven by power, when the machine is of this construction, is absolutely essential, as no one can turn the handle round with uniform velocity in all parts of the circle, and especially when a weight has to be lifted, and any jerking or irregular motion throws an unequal tension on the yarn and causes it to appear, when the fracture takes place, weaker than it really is. The speed at which the machine is turned is also very important, and although this is now quite recognised it was first pointed out by the author in his work on the cotton fibre written in 1882. From experiments then made, it was found that in order that the breaking strain of the yarn might correspond on the machine with that of yarn broken by the action of gravitation, by a suspended weight being hung upon the hank, the hand of the dial should travel the circle of the face in eight seconds. This time-element will enable any machine by the same maker to be set to the standard, because if the speed is higher the yarn will appear to be stronger, and if the speed is slower the yarn will appear weaker. The machine was tested every day during the time the experiments were being made by removing the catch which runs round in the circular rack and hanging a standard weight on to the upper hook, which caused the hands to traverse the dial, and so point to the graduations which correspond to the weight hung on the hook, a 56-lbs. weight causing the pointer on the dial to swing to 56, or two 56's to 112 lbs., which showed the machine to be perfectly accurate with the gravitation standard. The machine used was graduated up to 150 lbs.

A horizontal form of testing-machine is sometimes used,

in which, in place of lever and weight, the weight is replaced by a vessel hung on to a chain which passes over a pulley, and water is admitted by a suitable tap into the vessel until the weight breaks the lea, and the tensile strength is recorded on a dial attached to the machine. The author found that when proper precautions were employed, either of these different forms of machine gave accordant results. It may be noted also that generally, in testing, the results required are not so much the actual strength of the yarn as the comparative strength when tested against another yarn of the same counts. In both cases also there is a means of recording the elasticity of the yarn before breaking, but this can only be accurately measured by the single-thread testing machine, as in the case of the lea it is almost impossible to put the lea on to the testing hooks without having one thread tighter than the other, and this causes the threads to adjust themselves by drawing over the hooks until the tension is uniform, but this process destroys some of the elasticity before the strain comes on all the threads together.

Weighing of Yarn.—The balance used for weighing the yarn was a very delicate one, made specially for the purpose of chemical analysis, and turning the scales regularly with the $\frac{1}{1000}$th part of a grain, when the pans were loaded with 500 grains on each pan. It stood within a glass case, so as to shield it from currents of air and other disturbing influences. The front glass of the case slides up so as to enable the operator to reach the scales. Fig. 60 gives a good illustration of such a laboratory balance, in which an arrangement is made so as to take the weight off the knife edge, when the substance to be weighed is placed into the pans, and a small shaft with a milled head outside the case enables the beam to be set

free to work when the glass front is drawn down after the pans are loaded. Where great accuracy is not required a quadrant is used in place of a balance, by means of which the counts of the yarn is read off on a graduated semi-circular scale. The hank is simply hung upon the hook, and the balance weight by its angular deviation deflects the indicating needle from zero, at which it stands when

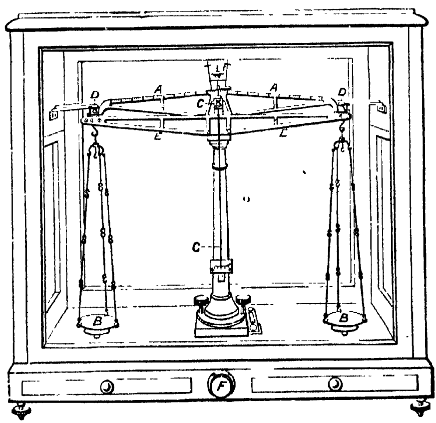

FIG. 60.—Chemical Balance.

there is no yarn hung on the hook, to the point indicating the counts. Fig. 61 gives a good representation of this quadrant. A scale pan may be substituted for the hook, and the accuracy of the machine may, at any time, be tested by placing the weights in the pan. The room in which the operations were performed was kept at a uniform temperature by a steam stove, and all the samples of yarn were exposed in the room for twenty-four hours before testing, so as to permit them to acquire, as far as possible,

the same conditions in regard to temperature and moisture, both of which have an effect on the strength of the yarn.

In place of a chemical scale or quadrant a Knowles' Balance is also sometimes used, which, when the weighing is being performed gives the reading of the counts direct, without the use of weights or a table of counts. Fig. 62 represents this balance. The scales are similar to an

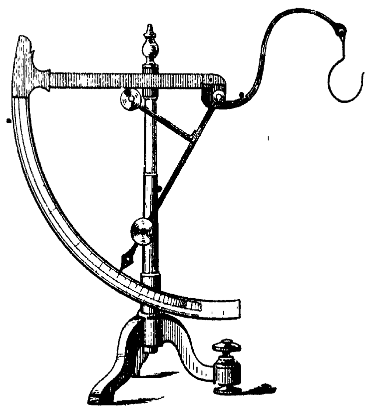

FIG. 61.—Yarn-Testing Quadrant.

ordinary balance, but on the top of the beam there is a roller or cylinder with six sides, each side of which has a different series of counts marked on it. With the scale six special standard weights are supplied and marked to correspond to the side to be used. This weight is put in the left-hand pan and the yarn in the right-hand, and a slider on the top of the beam, where equilibrium is attained, reads off the counts direct on the graduated hexagonal roller.

The samples of yarn themselves were selected from various makers, and were fair averages of a large production, and not picked samples, the author's intention being to arrive at the degree of perfection attainable in

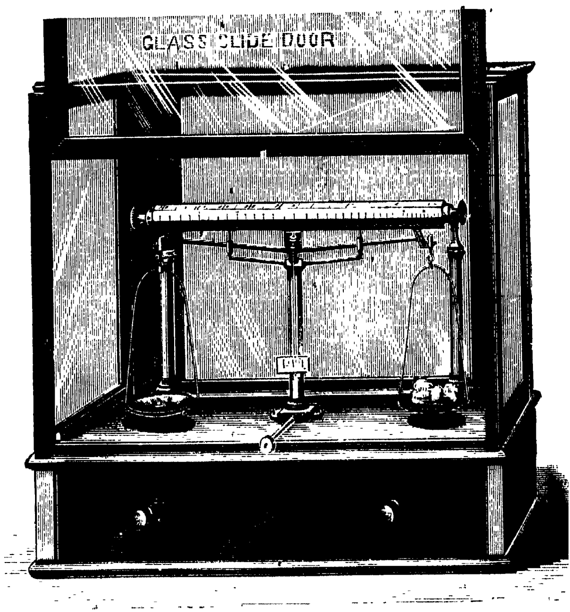

FIG. 62.—Knowles' Yarn Balance.

the ordinary yarns of commerce; but all the yarns were made by spinners who have a good name in the market for their respective productions.

The experiments extended over a much wider range of counts and samples than are here recorded, but the

general results were the same as given by these examples, and the author has therefore chosen only those which are generally used in the textile trades, and they may be taken as types of all other similar counts of yarn.

In all cases five experiments were made with the same thread, and four threads taken out of each sample promiscuously, and the results in the following tables may, therefore, from the care which was taken in the experiments, be relied upon as a basis for generalisation, and they may also be taken as a fair representation of what may be expected in the degree of perfection to which ordinary good commercial yarns usually attain.

[TABLE

SAMPLE A

20's Single, Mule Spun. All American Cotton

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	80	50·10		
	78	48·65		
	81	50·25		
	76	48·75		
	80	50·13	49·576	20·17
No. 2	73	47·83		
	84	50·23		
	84	51·31		
	86	52·14		
	84	52·31	50·764	19·69
No. 3	78	48·13		
	80	49·75		
	81	49·36		
	72	47·38		
	75	48·97	48·718	20·52
No. 4	72	47·36		
	78	49·62		
	78	50·13		
	73	48·52		
	79	49·36	48·998	20·40
	78·8		49·514	20·19

This is a good commercial yarn. The counts are on the average correct. The greatest variation both in strength and weight is in No. 2. Here the strength varies from 73 to 86 lbs. = 13 lbs. or 16·5 per cent on the average breaking strain, while the weight varies from 47·83 grains to 52·31 grains, or 4·48 grains, which is about 9 per cent on the average weight.

SAMPLE B

20's Single, Mule Spun. Made from Egyptian and American Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains	Average Weight.	Counts.
No. 1	102	50·13		
	106	51·93		
	101	51·37		
	100	50·37		
	106	51·30	51·020	19·60
No. 2	99	50·24		
	106	51·93		
	98	49·12		
	99	48·55		
	100	48·32	49·632	20·15
No. 3	100	50·12		
	98	52·13		
	97	48·35		
	99	48·15		
	98	19·38	49·626	20·15
No. 4	104	50·62		
	108	53·17		
	112	53·16		
	108	51·47		
	101	50·83	51·481	19·28
	102·2		50·531	19·795

This is a first-class mule yarn, the counts slightly coarse. The greatest variation is in No. 2 thread, where the strength varies from 98 to 106 lbs., or 8 lbs., which is rather less that 8 per cent on the average breaking strain. The variation in weight is greatest in No. 3, where it amounts to nearly 4 lbs., or about 8 per cent on the average weight.

SAMPLE C

20's Single, Water Twist. All American Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	80	48·13		
	75	47·58		
	84	48·25		
	82	48·36		
	80	48·83	48·230	20·73
No. 2	84	48·25		
	84	48·53		
	76	49·35		
	75	49·13		
	80	49·32	48·916	20·44
No. 3	73	47·21		
	72	47·30		
	80	49·31		
	75	50·13		
	81	50·35	48·860	20·46
No. 4	78	48·30		
	82	49·42		
	83	49·75		
	86	50·23		
	81	50·35	49·610	20·15
	79·5		48·904	20·445

This is a good using yarn. The counts very nearly correct. The greatest variation in strength is in No. 1 thread, from 75 to 84 lbs., or 9 lbs., which is about 11 per cent on the average strength. The greatest range in weight is in No. 3, from 47·21 grains to 50·35 grains = 3·14 grains, which is about 6·4 per cent on the average weight.

SAMPLE D

32's Single, Mule Spun. Oldham Limited Co.
All American Cotton.

Number of Experiments	Breaking weight per lea in lbs.	Weight in grains.	Average Weight	Counts.
No. 1	55	33·75		
	59	32·64		
	62	33·11		
	52	30·75		
	53	31·04	32·318	30·91
No. 2	52	31·22		
	57	31·47		
	52	30·46		
	56	32·14		
	56	32·34	31·526	31·72
No. 3	56	31·85		
	59	32·34		
	54	31·47		
	61	33·12		
	60	32·88	32·332	30·92
No. 4	48	30·73		
	52	30·14		
	52	30·57		
	49	29·51		
	50	30·75	30·340	32·96
	54·7		31·629	31·63

This is a favourite yarn in Lancashire. The counts are slightly coarse. The greatest variation in strength is in No. 1 thread, from 52 to 62 lbs., or 10 lbs., which is about 18·2 per cent on the average breaking strain. The greatest variation in weight is in the same thread, from 30·75 grains to 33·75 grains, or 3 grains, which is rather under 10 per cent of the average weight.

SAMPLE E

40's Single Twist, Super Bolton Mule Yarn. All Egyptian Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	55	25·53		
	53	25·02		
	56	25·14		
	54	25·31		
	54	25·41	25·282	39·55
No. 2	55	25·00		
	53	25·38		
	54	25·28		
	57	25·37		
	53	25·12	25·230	39·63
No. 3	54	25·31		
	56	25·43		
	55	25·38		
	53	25·13		
	57	25·37	25·324	39·48
No. 4	52	25·00		
	54	25·16		
	54	25·28		
	56	25·37		
	53	25·19	25·200	39·68
	54·1		25·259	39·585

This is a first-class mule yarn, spun down from 60's rovings. The counts are slightly coarse. The greatest variation is 4 lbs. in the breaking strain, which occurs in No. 2, 3, and 4 threads, which is about 7·3 per cent on the average strength. The weight is remarkably regular, the greatest variation being about 0·4 of a grain in No. 1 thread, which is less than 2 per cent on the average weight.

SAMPLE F

50's Single Twist, Bolton Mule Yarn. All Egyptian Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	32	19·12		
	38	20·14		
	35	20·12		
	38	20·24		
	31	19·92	19·908	50·23
No. 2	40	20·13		
	35	19·73		
	34	20·35		
	35	20·23		
	32	19·59	20·006	49·98
No. 3	39	20·01		
	31	19·23		
	36	20·54		
	35	20·23		
	31	20·30	20·062	49·84
No. 4	35	19·75		
	35	19·43		
	34	20·13		
	34	20·35		
	35	19·94	19·920	50·20
	35·2		19·974	50·06

This yarn is spun from the same roving as Sample E. The average counts are correct. The greatest variation in strength is in No. 2 thread, from 32 to 40 lbs., or 8 lbs., which is about 22 per cent of the average breaking weight. The greatest variation in weight is in No. 3 thread, from 19·23 grains to 20·54 grains, or 1·31, which is about 6·5 per cent of the average weight.

SAMPLE G

60's Single Twist. Bolton Mule Yarn. Made from Egyptian Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	33	16·25		
	31	16·68		
	31	17·31		
	31	17·22		
	34	16·84	16·860	59·31
No. 2	35	17·12		
	34	17·00		
	34	17·48		
	30	16·58		
	33	16·95	17·026	58·73
No. 3	32	16·38		
	30	16·45		
	29	16·25		
	32	16·83		
	31	17·13	16·608	60·21
No. 4	35	17·38		
	34	17·12		
	32	17·37		
	30	17·00		
	32	17·35	17·244	58·00
	32·3		16·934	59·06

This is a first-class carded yarn. The counts are coarse, only one thread being full counts. The greatest variation in strength is in No. 2 and No. 4 threads, from 30 to 35 lbs., which is about 15 per cent of the average breaking strain. The greatest variation in weight is in No. 1, from 16·25 grains to 17·31 grains, or 1·06 grains, which is about 6 per cent of the average weight.

SAMPLE H

60's Single Twist. Super Combed Mule Yarn. Egyptian Cotton.

Number of Experiments	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	34	17·75		
	36	17·04		
	32	17·15		
	36	17·16		
	31	16·75	17·170	58·21
No. 2	35	17·23		
	36	17·23		
	31	17·25		
	32	17·11		
	33	16·84	17·138	58·35
No. 3	30	16·61		
	31	16·23		
	30	16·75		
	32	17·11		
	30	17·00	16·752	59·69
No. 4	36	17·25		
	35	16·84		
	36	17·14		
	34	17·25		
	33	16·91	17·084	58·53
	33·4		17·036	58·70

This is one of the best mule yarns in the market. The counts are heavy. The greatest variation in the breaking strain is in No. 1 and No. 2 threads, from 32 to 36 lbs., or 4 lbs., which is about 12 per cent on the average breaking strain. The greatest variation in counts is in No. 1 thread, from 16·75 to 17·75 grains, or about 6 per cent of the average weight.

SAMPLE P

Twofold 40's, Full Twist Twiner Yarn. American Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	100	51·23		
	109	54·13		
	96	50·12		
	99	52·83		
	100	50·14	51·690	19·34
No. 2	99	52·10		
	112	54·21		
	104	52·13		
	100	51·91		
	98	52·13	52·502	19·04
No. 3	95	50·10		
	108	52·11		
	112	54·05		
	98	51·37		
	95	50·83	51·712	19·33
No. 4	108	53·12		
	98	52·16		
	98	51·47		
	104	52·85		
	104	52·13	52·406	19·08
	101·8		52·077	19·19

This is a first-class American yarn. The counts are heavy. The greatest variation in strength is in No. 3 thread, from 95 to 112 lbs., or 17 lbs., which is about 17 per cent on the average breaking strain. No. 2 thread exhibits an almost equally wide variation, from 98 to 112 lbs. The greatest variation in counts is in No. 1 thread, where the weight ranges from 50·12 to 54·13 grains, or 4·01 grains, or about $7\frac{1}{2}$ per cent on the average weight.

SAMPLE J

Twofold 40's, Full Twist Twiner Yarn. Egyptian Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts
No. 1	109	53·10		
	112	52·10		
	108	52·13		
	100	51·32		
	100	51·52	52·031	19·21
No. 2	112	52·71		
	104	51·42		
	98	51·14		
	102	52·00		
	108	52·41	51·936	19·25
No. 3	109	52·00		
	112	53·00		
	106	52·43		
	106	51·34		
	105	51·83	52·120	19·18
No. 4	110	52·14		
	110	52·34		
	114	53·10		
	112	53·41		
	111	53·17	52·832	18·92
	107·4		52·230	19·14

This is a splendid yarn—one of the best in the market. The counts are slightly coarse. The greatest variation in strength is in No. 2 thread, from 98 to 112 lbs., or 14 lbs., which is about 13 per cent on the average breaking strain. The greatest range in counts is in No. 3 thread, where the weight varies from 51·34 to 53 grains, or 1·66, or about 3 per cent on the average weight.

SAMPLE K

Twofold 40's, Supér Frame. Egyptian Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains	Average Weight.	Counts.
No. 1	115	50·00		
	112	50·41		
	112	49·38		
	110	49·56		
	110	50·37	49·911	20·02
No. 2	99	49·13		
	103	49·35		
	110	49·56		
	105	49·83		
	111	49·67	49·508	20·19
No. 3	120	50·43		
	105	49·38		
	108	48·85		
	99	48·53		
	100	48·84	49·206	20·32
No. 4	112	51·36		
	108	51·21		
	114	50·65		
	118	50·95		
	107	50·36	50·906	19·64
	108·9		49·891	20·04

This is a special yarn made with a view to extra strength, the twist per inch being 21 turns. The counts are full. The greatest variation in strength is in No. 3 thread, from 99 to 120 lbs., or 21 lbs., which is rather over 19 per cent of the average breaking strain. The greatest variation in weight is in No. 3 thread, from 48·53 to 50·43 grains, or 1·9, which is about 4 per cent on the average weight.

SAMPLE L

Twofold 38's, Super Frame. Egyptian Cotton.

Number of Experiments	Breaking weight per lea in lbs	Weight in grains.	Average Weight.	Counts.
No. 1	130	52·103		
	124	52·381		
	130	52·661		
	127	52 820		
	130	52·750	52·543	19·03
No. 2	140	52·583		
	135	53·012		
	142	53·100		
	141	53·112		
	138	52·831	52·927	18·89
No. 3	128	52·143		
	126	52·321		
	132	52·621		
	134	52·336		
	130	52·128	52·309	19·11
No. 4	132	52·136		
	126	52·731		
	124	52·834		
	120	52·114		
	130	52·912	52·545	19·03
	131		52·581	19·01

This is a special yarn made purposely for extra strength and evenness, and is spun down from 90's rovings. The counts are full. The twist is = 21 turns in 40's. The greatest variation in strength is in thread No. 4, from 120 to 132 lbs., or 12 lbs., which is a little over 9 per cent on the breaking weight. The greatest variation in counts is in No. 4 thread, from 52·114 to 52·912 grains, or ·798 grain, which is rather more than $1\frac{1}{2}$ per cent on the average weight.

SAMPLE M

Twofold 60's Frame Yarn, made from Egyptian Cotton.

Number of Experiments.	Breaking weight per lea in lbs	Weight in grains	Average Weight.	Counts.
No. 1	74	32·83		
	74	32·94		
	70	32·81		
	74	32·92		
	74	32·95	32·890	30·40
No. 2	76	33·25		
	74	33·12		
	71	32·91		
	73	33·00		
	72	33·15	33·086	30·22
No. 3	78	33·85		
	78	33·76		
	79	33·92		
	77	33·52		
	77	33·40	33·690	29·68
No. 4	68	33·25		
	70	32·85		
	69	32·93		
	74	33·15		
	74	33·04	33·044	30·26
	73·8		33·177	30·14

This is a strong regular yarn. The counts are full. The greatest variation in strength is in No. 4 thread, from 68 to 74 lbs. = 6 lbs., which is about 8 per cent on the average breaking strain. The greatest variation in counts is in No. 3 thread, from 33·40 to 33·92 grains = 0·52 grains, or about 1½ per cent on the average weight.

SAMPLE N

Twofold 60's Twiner Yarn. All Egyptian Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	92	33·85		
	86	32·75		
	88	32·93		
	86	32·83		
	82	32·75	33·022	30·28
No. 2	80	32·94		
	83	32·83		
	81	32·95		
	80	32·93		
	82	32·99	32·928	30·36
No. 3	90	33·21		
	89	33·25		
	95	33·36		
	92	33·28		
	90	33·21	33·265	30·06
No. 4	84	33·00		
	80	33·16		
	81	33·04		
	85	33·24		
	84	33·28	33·144	30·17
	85·5		33·090	30·22

This is a first-class yarn. The counts are full. The greatest variation in strength is in No. 1 thread, from 82 to 92 lbs. = 10 lbs., or about $11\frac{3}{4}$ per cent on the average breaking strain. The greatest variation in counts is in No. 1 thread, from 32·75 to 33·85 grains = 1·1 grains, or about $3\frac{1}{3}$ per cent on the average weight.

SAMPLE O

Twofold 80's Twiner Yarn. Egyptian Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	59	25·43		
	61	26·34		
	64	26·00		
	63	25·38		
	60	26·00	25·830	38·71
No. 2	64	26·13		
	55	25·37		
	65	25·29		
	56	25·87		
	62	26·13	25·758	38·82
No. 3	62	25·83		
	66	26·32		
	63	26·10		
	65	26·53		
	63	26·12	26·180	38·19
No. 4	60	25·91		
	64	26·83		
	54	24·75		
	60	26·12		
	54	25·12	25·746	38·84
	61		25·878	38·64

This is a good using yarn. The counts are heavy. The greatest variation in strength is in No. 4 thread, from 54 to 64 lbs. = 10 lbs., which is equal to $16\frac{2}{5}$ per cent. A similar variation occurs in No. 2 thread, from 55 to 65 lbs. The greatest variation in weight is from 24·75 to 26·83 grains = 2·08 grains, which is equal to about 8 per cent on the average weight.

SAMPLE P

Twofold 120's Frame Yarn. All Egyptian Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	50	16·25		
	53	16·45		
	51	16·62		
	54	16·83		
	50	16·35	16·500	60·60
No. 2	48	17·13		
	52	17·00		
	50	16·43		
	54	16·59		
	52	16·83	16·796	59·53
No. 3	54	17·35		
	56	17·12		
	51	16·93		
	48	16·65		
	52	16·83	16·976	58·90
No. 4	50	16·68		
	48	16·23		
	52	16·94		
	52	16·75		
	51	17·04	16·728	59·78
	51·4		16·750	59·70

This is a good yarn. The counts are slightly heavy. The greatest variation in strength is in No. 3 thread, from 48 to 56 lbs. = 8 lbs., or about $15\frac{1}{2}$ per cent on the average breaking weight. The greatest variation in weight is in No. 4 thread, from 16·23 to 17·04 grains = 0·81 grains, or about 4·8 per cent of the average weight.

SAMPLE Q

Twofold 120's Super Combed Frame. All Sea Island Cotton.

Number of Experiments.	Breaking weight per lea in lbs.	Weight in grains.	Average Weight.	Counts.
No. 1	61	16·12		
	59	16·00		
	66	17·13		
	63	17·01		
	64	16·83	16·618	60·17
No. 2	66	17·25		
	64	16·43		
	68	16·83		
	65	16·28		
	63	16·67	16·692	59·91
No. 3	68	17·31		
	68	17·14		
	62	16·83		
	60	16·25		
	64	16·83	16·872	59·27
No. 4	63	16·67		
	60	16·83		
	64	16·94		
	65	16·58		
	59	16·37	16·678	59·96
	63·6		16·715	59·82

This is one of the best yarns in the market, made for quality entirely regardless of expense. The counts are slightly heavy. The greatest variation in strength is in No. 3 thread, from 60 to 68 lbs. = 8 lbs., or about $12\frac{1}{2}$ per cent of the average breaking weight. The greatest variation in weight is in No. 3 thread, from 16·25 to 17·31 grains = 1·06 grains, or about 6 per cent of the average weight.

In looking at the general results of the testings of these yarns attention is called to the wide variation which the

different samples of single yarn present in the regularity of the breaking strain,—the variation, in fact, ranging from 10·5 per cent in sample E to 22 per cent in sample H. The best results are obtained in those yarns which are spun down from higher numbers, and which, in consequence of the lower drafts in the spinning and also the proportionately better quality of the raw material for the counts, are relatively of a better quality.

The deviation presented by the single yarns in regard to weight or counts is not so wide as in the strength, and only varies from 2 per cent in sample E to 10 per cent in sample D, being most regular in the spun-down yarns.

These variations will be clearly seen by examining the following table, and it will be noticed that in the first four samples the result is the same, viz. 14 per cent.

TABLE OF STRENGTH AND VARIATION IN SINGLE YARNS, TESTED ONE LEA AT ONCE

Sample	Counts.	Cotton.	Quality.	Maximum strength in Pounds.	Minimum strength in Pounds.	Average strength in Pounds.	Greatest variation in Pounds.	Variation per cent.
A	20s	All American mule	Common	86	72	78·8	14	17
B	20s	Egyptian and American mule	Good	112	97	102·2	14	14·2
C	20s	All American frame	,,	86	72	79·5	14	17
D	32s	All American mule	,,	62	48	54·7	14	25
E	40s	All Egyptian mule	,,	57	52	54·4	5	10·5
F	50s	All Egyptian mule	,,	40	32	35·2	6	16·5
G	60s	All Egyptian mule	,,	35	31	32·3	4	12·5
H	60s	All Egyptian mule	Super combed	36	30	33·4	6	22

If we compare this table with the corresponding table of single yarns tested one thread at a time on p. 322, it will be noticed that there is very much less variation per cent. In this table the greatest is, as already seen, 22 per cent in sample H and 16·5 per cent in sample E, while in the single threads the greatest variation per cent is 72 in sample H, which is 45's American, and the least 23 per cent in sample C, which is 26's all American.

It is also interesting to note what a great loss per lea there is in testing the yarn, arising mostly from the fact that the strain does not in testing the strength of the lea come equally on all the threads composing it at the same time.

Taking the average breaking strain of one thread of good American 20's single, as shown by the table of strength in single yarns taken one thread at a time on p. 309, at 12 oz., then, since there are 80 threads in each lea when wound on to a $1\frac{1}{2}$-yard reel, and that when it is being tested by being placed over two hooks on the lever yarn-testing machine shown in Fig. 59 there are 80 threads on each side and passing round the two hooks, then, if the yarn was in such condition that the strain came equally on all the threads at once, the breaking strain of the lea ought to be $80 \times 2 \times 12 = 1920$ oz. $= 120$ lbs., whereas, as seen from the table above, it is only a little under 79 lbs. (78·8), a loss of 40 lbs. or practically 30 per cent.

In the same way, if 40's single Egyptian is taken, as in sample G in the table given on p. 315, it shows the average strength, taken thread by thread, to be 7 oz. per thread, and this ought to produce in the same single yarn tested by the lea $80 \times 2 \times 7$ oz. $= 1120$ oz. or 70 lbs., whereas, as shown by the above table when tested by the lea, it only gives an average strength of about 54·5, or a loss of 15·5 lbs., or about 22 per cent loss.

In twofold yarns the variation in the breaking strain is more uniform, the extreme variation being from 8 per cent in sample M to 19 per cent in sample K. If, however, we leave out sample M, which gives remarkably good testings, the extreme variation is only from 11 to 19 per cent. It is somewhat remarkable that the greatest variation in this respect occurs in a super frame yarn. In this sample, however, the twist is below the usual standard, and it will be noticed that, as a rule, slack twisted yarns are subject to greater variations in strength than full twisted yarns. This probably arises from the fact that the twist in yarn has always a tendency to creep or run into the thinnest or most uneven parts of the yarn; and where the twist is slack this is specially noticeable, and tends to produce a greater variation.

With regard to variation in weight or counts, the twofold yarns appear to vary nearly as much as single yarns, the extreme variation being from 1½ per cent in sample M to 8 per cent in sample O. The least variation, both in strength and counts, occurs in sample M, which is a frame yarn.

Until the author conducted these experiments, he was of opinion that there was a much greater difference in regard to the regularity in the breaking strain of single and twofold yarns, since, where two threads are doubled together, there appeared to be a much greater chance of uniformity, as the irregularities in the two threads would tend to neutralise each other. It appears, however, that this advantage is neutralised by the difficulty of keeping the two threads at a uniform tension in the process of doubling and putting in the twist, and which tends to cause one thread to wind spirally round the other, like the thread of a screw round the cylinder which forms its core,

and thus when the strain is thrown on to the double thread one has more pressure to carry than the other. This is easily seen by the eye in thick counts, and specially when slackly twisted. There is always, also, the danger of single snarls, which in the case of single yarns draw out, and are frequently the strongest part of the thread; but in twofolds these snarls, even when scarcely discernible to the naked eye, cause all the strain to be thrown on to the other thread, which, being only single, gives way more readily.

It seems, therefore, from these and other causes, that twofold yarns are liable to as wide variation as singles, both in strength and counts.

It is interesting also to note, as has already been done with the single yarns, the great loss sustained by testing the twofold yarn in the lea as against the single thread, which is, after all, the more important matter. The breaking strain and variations in the samples tested in the lea are clearly seen in the following table :—

[TABLE

TABLE OF STRENGTH AND VARIATION IN TWOFOLD YARNS, WHEN TESTED ONE LEA AT ONCE

Sample.	Counts.	Cotton.	Quality.	Maximum strength in Pounds.	Minimum strength in Pounds.	Average strength in Pounds.	Greatest variation in Pounds.	Variation per cent.
I	2/48's	All American twiner	Good	112	95	102	17	17
J	2/48's	All Egyptian twiner	,,	114	98	107	16	16
K	2/48's	All Egyptian frame	Super	118	99	109	19	15
L	2/38's	All Egyptian frame	,,	142	120	131	22	17
M	2/60's	All Egyptian frame	,,	79	68	74	11	14
N	2/60's	All Egyptian twiner	,,	95	80	85	15	19
O	2/80's	All Egyptian twiner	,,	66	54	61	12	20
P	2/120's	All Egyptian frame	,,	56	48	51	8	16
Q	2/120's	All Egyptian frame	Super combed	68	59	64	9	14

It is interesting to note also, as in the case of the single yarns, how much loss there is in testing the twofold yarns by the lea in place of by the single thread.

Take the case of 2/40's Egyptian twiner, sample J, in the above table, where the average breaking weight is 107 lbs. Looking at the table of breaking weights when tested thread by thread in twofold yarns given on p. 327, it will be found that the breaking weight of sample C, which is 2/40's Egyptian twiner, is 21 oz., so that per lea $80 \times 2 \times 21 = 33$[illegible]oz. $= 210$ lbs., whereas the above table shows the average is only 107, or a loss of nearly 50 per cent.

In the same way 2/60's twiner in sample N in the above table, which breaks on the average when tested in the lea at 85 lbs., if a similar comparison is made ought to

break at $80 \times 2 \times 14\frac{1}{4} = 2280$ oz. $= 142$ lbs., or a loss of 67 lbs., nearly 80 per cent.

Before passing away from the consideration of the strength of various counts of yarn it may not be uninteresting to inquire how far there is utilised the total strength of the raw material or fibres out of which any yarn is composed. It may seem at first sight as if it was impossible to calculate the theoretical strength of a thread, but if we know the tensile strain which the individual fibres which compose it will carry before they break, and the number of fibres or filaments in the cross-section of the thread, the calculation is easily made. It must not be supposed that there are always the same number of filaments in the cross-section of the threads of the same counts, as they vary very much with the nature of the cotton, and in these calculations the average, when Middling Memphis with staple, and Fully Good Fair Egyptian are used, has been taken.

Of course, this calculation supposes that all the fibres are sufficiently twisted into the thread to prevent their slipping, or drawing out without breaking, and as this can never be perfectly accomplished, we must make a considerable allowance for this drawing-out action, especially in slack twisted yarns.

In the following tables, however, no such allowance is made, because it was found practically impossible to arrive at any satisfactory data as to what percentage this source of weakness amounts to. Much depends on the twist in the yarn, and in these experiments yarns were selected with the theoretical twist per inch.

This twist is that which experience shows to be such that the yarn will finally set without curling, and when it is exceeded there is danger of introducing other faults into

the yarn, which more than take away the advantage derived from the extra strength given by the extra twist, except for special purposes.

The following tables exhibit the results obtained from calculations and experiments on American and Egyptian cotton.

AMERICAN COTTON

Counts.	Average number of fibres in cross-section of thread.	Calculated strength per lea in lbs.	Observed strength per lea in lbs.	Percentage of total strength utilised.	Percentage of total strength lost.
20's Watertwist	230	388	80	20·6	79·4
32's Mule .	144	240	50	20·8	79·2
40's ,, .	120	194	40	20·6	79·4
50's ,, .	92	155	30	19·3	80·7
30's Twofold .	300	500	130	26·0	74·0
40's ,, .	225	380	100	26·3	73·7
50's ,, .	180	300	75	25 0	75·0

In the Egyptian cotton, as we have already seen, the fibres are smaller in diameter, and we have therefore a larger number in the cross-section of any given thread, as will be observed by comparing the two tables.

EGYPTIAN COTTON

Counts.	Average number of fibres in cross-section of thread.	Calculated strength per lea in lbs.	Observed strength per lea in lbs.	Percentage of total strength utilised.	Percentage of total strength lost.
40's Single mule	161	234	50	21·3	78·7
50's ,,	129	188	38	20·2	79·8
60's	107	156	30	19·2	80·8
40's Twofold .	320	450	120	26·6	73·4
50's ,, .	240	360	96	26·6	73·4
60's ,, .	200	300	83	27·6	72·4
70's ,, .	180	255	70	27·4	72·6
80's ,, .	160	220	60	27·2	72·8
90's ,, .	140	200	50	25·0	75·0

In looking at these tables, it seems that very little more than 20 per cent of the total strength of the raw material is utilised, whether it be American or Egyptian cotton, when it is spun into single yarns, and that the percentage of loss increases as the yarn becomes finer. Of course, in this large loss of nearly 80 per cent are included all the imperfections which arise from the drawing out of the fibres, from the imperfections in the spinning, and the want of uniformity in the strength of the raw material, which in the calculated strength are supposed to be perfectly uniform. In twofold yarns the results are rather better by about 6 per cent. Here the percentage of loss increases as the counts become finer. In making these tests, in all cases yarns were selected spun down from the highest counts, and therefore made from the same cotton—that is to say, the American singles were all spun down from 50's rovings, and the Egyptian singles from 60's rovings, and in the twofold yarns the American qualities were all produced from the same roving and cotton as the 2/50's, and the Egyptian twofolds from the same rovings and cotton as the 2/90's. Had the yarns been spun in the reverse way, viz. upwards from the lower qualities to the higher, the percentage of loss as we reached the higher counts would probably have been very much larger.

The question of the regularity with which twist can be put into yarns is also very important, because upon this depends to a large extent the uniformity in strength.

To determine this point the author made a series of experiments, from which we have selected five samples. Four of them are the same yarns and threads, which were experimented upon for the strength and regularity in counts, and are marked with the same letters, so as to facilitate reference.

The twist was determined by a small machine made specially for the purpose. It consists of a sliding bar graduated in inches, which carries upon it a horizontal spindle, which holds one end of the thread, and the revolutions of which are registered by an automatic counter. The other end of the thread is held in a fixed slit or vice, carried on a horizontal spindle, which holds it tight and prevents any twist running either in or out of the portion of the thread between itself and the end of the revolving spindle. The appearance and structure of this machine will be easily understood by reference to Fig. 63, which

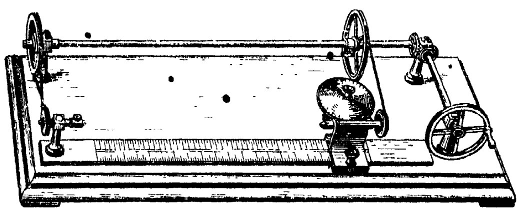

FIG. 63.—Yarn Twist Testing Machine.

is a correct representation of it. The recording dial is double, and can easily be set back to zero without turning the machine, by simply releasing the milled head seen above the dial, when the top plate can be turned in either direction and clamped to the position required by screwing up the nut again. When the machine is about to be used the sliding bar is set to the number of inches required to be measured, and the thread slipped into the two jaws and made fast. The small wheel is then turned round in the proper direction, and this revolves a horizontal shaft from which the two spindles holding the ends of the thread are driven, until all the twist is out of the yarn,

and the number of turns is read off the dial, which was set to zero before commencing.

It is quite clear that since all doubling and spinning machines are so arranged that a certain fixed amount of twist is put into a certain number of inches of yarn, if the material of which the thread is composed was equally elastic in every part, and equally even in diameter, there would be perfect uniformity in twist; and even as it is, with all the imperfections in this respect, if a sufficient number of inches, such as 100, is taken we reach a wonderful uniformity in results, depending upon the law of averages. The author, however, took 5 inches and 1 inch as the standard lengths for experiment, and in each thread operated upon he took these lengths five times consecutively, so as to obtain an average of results. The second column in the tables, therefore, presents the number of turns which were present in 5 inches of yarn without regard to their distribution through these inches. The fourth column gives the number of turns which were present in each thread taken inch by inch. The third column represents the average number of turns per inch when the turns are measured 5 inches together, and the fifth column the average number of turns per inch when the turns are measured inch by inch.

As in the case of the samples which were used for testing variations in the strength of yarn, he experimented upon a much larger number of samples than are given here; but as the general results derived from the tests were very similar to those which are derived from these examples, it would only have extended the work without affording additional information.

[TABLE

SAMPLE R

Twofold 20's Twiner Yarn. Made from American Cotton.

Number of Experiments	Taken 5 inches together.	Average per inch.	Taken inch by inch.	Average per inch.
No. 1	93		21	
	87		19	
	92		17	
	90		17	
	85	17·88	16	18·0
No. 2	84		18	
	98		20	
	101		18	
	100		18	
	95	19·12	19	18·6
No. 3	93		21	
	85		18	
	98		18	
	100		15	
	93	18·76	19	18·2
No. 4	95		18	
	90		20	
	100		22	
	89		16	
	95	18·76	17	18·6
		18·63		18·35

The greatest variation in the twist taken 5 inches together occurs in No. 2 thread, from 84 to 101 turns = 17 turns, or 18 per cent of the average number. The greatest variation when taken inch by inch occurs in No. 3 thread, from 15 to 21 turns = 6 turns, or nearly 33 per cent of the average turns. The same percentage in variation also occurs in No. 4 thread, from 16 to 22 turns = 6 turns. The average number of turns taken by the two methods and averaged for the four threads is very nearly equal, being about $2\frac{1}{2}$ per cent difference.

SAMPLE I

Twofold 40's Twiner Yarn. Made from American Cotton.

Number of Experiments.	Number of turns taken 5 inches together.	Average per inch.	Number of turns taken inch by inch.	Average per inch.
No. 1	119		27	
	139		25	
	128		23	
	135		26	
	136	26·28	32	26·6
No. 2	124		21	
	133		26	
	113		27	
	125		25	
	140	25·40	31	26·0
No. 3	133		20	
	135		25	
	144		29	
	126		25	
	110	25·92	32	26·2
No. 4	123		25	
	116		23	
	134		24	
	126		26	
	116	24·60	24	24·4
		25·55		25·8

The greatest variation in twist taken 5 inches together is in No. 3 thread, from 110 to 144 turns = 34 turns, or a little over 26 per cent of the average number of turns. The greatest variation when taken inch by inch is in No. 2 thread, from 21 to 31 turns = 10 turns, or about 38 per cent of the average number. The general average taken both ways is very similar, the difference being only about 1 per cent.

SAMPLE M

Twofold 60's Frame Yarn. Made from Egyptian Cotton.

Number of Experiments.	Taken 5 inches together.	Average per inch.	Taken inch by inch	Average per inch.
No. 1	128 131 132 138 143	26·88	22 29 25 29 23	25·6
No. 2	130 132 140 126 132	26·40	23 30 28 22 27	26·0
No. 3	140 138 130 126 126	26·40	22 27 35 28 21	27·2
No. 4	132 127 133 140 130	26·48	32 28 29 21 24	26·8
		26·54		26·4

The greatest variation in twist taken 5 inches together is in No 1 thread, from 128 to 143 turns = 15 turns, or a little above 11 per cent of the average turns. The greatest variation taken inch by inch is in No. 3 thread, from 22 to 35 turns = 13 turns, which is equal to 50 per cent of the average number of turns. The average obtained by the two methods is very nearly equal.

SAMPLE O

Twofold 80's Twiner Yarn. All Egyptian Cotton.

Number of Experiments.	Taken 5 inches together.	Average per inch	Taken inch by inch.	Average per inch.
No. 1	170		26	
	156		30	
	178		38	
	180		39	
	190	34·96	40	34·60
No. 2	188		40	
	190		40	
	158		34	
	168		25	
	165	34·76	37	35·20
No. 3	178		25	
	159		29	
	190		41	
	178		43	
	166	34·84	39	35·40
No. 4	186		42	
	170		40	
	164		28	
	159		26	
	180	34·36	32	33·60
		34·73		34·70

The greatest variation taken 5 inches together occurs in No. 1 thread, from 156 to 190 turns = 34 turns, or about 20 per cent of the average number. The greatest variation taken inch by inch is in No. 4 thread, from 26 to 42 turns = 16 turns, or about 46 per cent of the average number of turns. The average number obtained by the two methods is about the same.

SAMPLE Q

Twofold 120's Super Combed Frame Yarn. Made from Sea Island Cotton.

Number of Experiments	Number of turns taken 5 inches together	Average number of turns	Number taken inch by inch.	Average number of turns.
No. 1	174		38	
	212		44	
	210		37	
	212		35	
	189	39·88	43	39·40
No. 2	195		34	
	198		40	
	194		36	
	190		38	
	188	38·60	39	37·40
No. 3	208		39	
	212		38	
	198		43	
	204		40	
	206	41·12	42	40·10
No. 4	212		44	
	209		40	
	190		39	
	188		36	
	201	40·00	40	39·80
		39·90		39·25

The greatest variation in the number of turns taken 5 inches together is in No. 1 thread, from 174 to 212 turns = 38 turns, which is about 19 per cent of the average. The greatest variation taken inch by inch is in No. 1 thread, from 35 to 44 turns = 9 turns, or about 23 per cent of the average. The average obtained by the two methods differs by about $1\frac{3}{4}$ per cent.

In looking over these examples it may be noticed that when the number of turns per inch are taken five inches together, the greatest average variation is very nearly $18\frac{1}{2}$ per cent, ranging indeed from 11 up to 26 per cent. When the counting is done inch by inch this variation becomes much greater, being on the average, indeed, nearly twice as great, or 37 per cent. The range is from 23 up to 50 per cent. Notwithstanding this, the average number of turns which is obtained by each of these methods is wonderfully uniform, since its greatest range is only 2 per cent.

One of the most fruitful causes of irregularity in the twist of yarns arises from the fact that whenever any irregularity occurs in either of the threads which are doubled together, there is a tendency for the twist to run out of these thick places and accumulate in those parts of the thread where the diameter is smaller. This peculiarity, which is detrimental to double yarns, is really an advantage in single yarns, and specially in those which are spun upon mules, because the twist accumulating in the thin parts of the thread tends to strengthen the weak places, and thus to increase the average strength of the thread, which, like a chain, depends upon the weakest link. In mule spinning this action greatly tends both to strength and uniformity, because when the yarn is being delivered by the rollers wherever a thin place comes out the twist runs into it, and by strengthening this part prevents any further drawing-out action, while the thick places are still acted upon by the gain in the carriage and drawn thinner. In throstle spinning the distance between the rollers and the bobbin is too small to permit this action to take place to any extent, and, also, there is no drawing-out action after the thread has left the rollers, except any slight extension which may be due to the drag of the bobbin.

The variations in diameter in the raw material are scarcely less important than those in length of staple, because it will be evident to all that no degree of mechanical perfection in spinning can exercise more than an equable power of distribution of the fibres in the thread; and if these vary in their thickness, unless there has previously been a perfectly uniform distribution of the fibres in the roving, it will be perfectly impossible to secure uniformity in the yarn. It may surprise some when it is stated that in order to accomplish this in the spinning of fine yarns, the average is taken several millions of times. It is impossible also to leave out of account the spiral character of the cotton fibre, because upon this peculiarity to a large extent depends one of the characters which render it possible to be used as a raw material for yarn spinning.

It has already been seen that different cottons vary much in this characteristic; also, that this peculiarity seems to manifest itself very shortly after the opening of the boll, and to be increased by the gradual accumulation of secondary deposits and the collapsing and desiccation of the fibre after the separation from the seed. The strength which any yarn possesses depends not only upon the ultimate strength of the fibres of which it is composed, but also upon the degree of friction which the surfaces of the individual fibres possess, and which enable them to receive the twist of the yarn, and thus resist being drawn out when the thread is subjected to strain. In the case of wool, this friction is due to the serrated edges of the scales which cover the epidermal layer, and which interlock in the process of twisting and felting. In the case of cotton, the friction is no doubt due to the twisted form assumed by the collapsed tube; and when the tube walls are sufficiently thick to resist this twisting action, or the fibres sufficiently

short to enable the twist of the tube to run out at the end, by enabling the fibre to uncoil itself, the yarn made out of such cotton will require more twist putting in mechanically in order to obtain the same strength. Remarking on this point, a writer[1] has observed: "When cotton fibres, as in the process of spinning, range themselves in the grooves of contiguous fibres, the effect of the twist is, that the greater the strain on the yarn the closer is the mutual grip of the fibres, which may break, but will not slip asunder.

"Cotton fibres vary very much in the character of their twist, which is always present in the best fibres, though some inferior staples scarcely exhibit any.

"Cotton wool seems, in fact, to be made up of naturally formed strands, in which nature has in a great measure anticipated the work of the spinner. I am not acquainted with any other vegetable hair showing a similar twist, nor can I discover a trace of any property likely to be beneficial to the cotton plant itself in this remarkable structure."

It appears to be an undoubted fact that cultivation tends to increase the amount and regularity of this twisting action, from whatever cause it may arise, since in the wild cotton which is indigenous to Africa there is very little of this character exhibited, and it is also noticeable that many of the fibres show a deposition of secondary matter in the form of spiral filaments, or fibrillæ, lining the interior of the tube. This appears to me to be very important, because it seems to indicate that the method in which the cotton fibre wall is increased in thickness is really the same as is usual amongst vegetable cells, viz. by the accumulation of secondary deposits upon the outer pellicle, and that these deposits in the uncultivated fibre may even

[1] *Microscopic Characters of the Cotton of Commerce*, by Rev. H. H. Higgins, M.A., p. 11.

assume the spiral form, which forms so conspicuous a feature in many vegetable structures, and which is so markedly absent in the cotton of commerce. Speaking on this point Mr. Higgins remarks: "In some of the fibres of the wild cotton the fibrillæ show a tendency to a longitudinal rather than a spiral growth within the tube, which in such instances becomes more or less flattened or compressed, thus assuming one of the distinctive characters of the fibres of cultivated cotton. In most of the wild fibres there are numerous fibrillæ, having a spiral direction from left to right. In the flattened fibres in which the fibrillæ are disposed, more or less longitudinally, their spiral tendency seems to be converted into a spiral twist of the fibre itself, having also a direction from left to right. A similar, but more perfect form of spiral twist, is one of the most prominent microscopic characters of the cultivated fibre."

While this variation in diameter of the fibres is undoubtedly the source of great difficulty in the mere mechanical operations through which the cotton has to pass, the difficulty arising from general variations in the structure of the fibre, both mechanical and chemical, is greatly increased when we have to consider that there are also in the various stages of the manufacturing process many chemical changes to be included, as is the case with all dyed yarns. Here the variations in the character of the fibre present a more serious difficulty, because the changes depend upon a series of molecular actions, which are more minute and less under the control of man.

GLOSSARY

OR, EXPLANATIONS OF SOME OF THE TERMS USED IN THIS WORK

Achromatic condenser. A compound lens used for concentrating the light on to the object under the microscope.

Affinity. Chemical attraction or cohesion.

Albuminous matter. Matter possessing the same properties as the white of an egg.

Alizarine. The red colouring matter of the madder root; now obtained from coal-tar.

Amorphous. Possessing no regular structure; like jelly or treacle.

Analysis. The breaking up of a substance into its simplest constituents, so as to determine their qualitative or quantitative relations.

Aniline. One of the colouring matters derived from coal-tar.

Anthers. The lobes attached to the stamens which carry the pollen in a flower.

Atom. The smallest part into which any elementary substance can be divided.

Atomic. Relating to atoms.

Atomicity. The power which an atom possesses of holding one or more other atoms in combination.

Automatic. A machine which acts without the necessity for human supervision.

Axis. In a plant the centre round which the floral whorls are arranged. In the microscope the axis is represented by a line drawn centrically through both the eye-piece and object-glass.

Bast Fibres. Fibres derived from the inner bark of dicotyledonous plants.

Battery. When applied to microscopy, signifies a full range of eye-pieces and object-glasses, giving a variety of magnifying power.

Binocular. A microscope with two tubes and eye-pieces, so that both eyes can be used for observation at once.

Boll. The seed-vessel of the cotton plant when expanded by the cotton fibre.

Calyx. The outer covering or cup of a flower.

Cambium layer. Mucilaginous cells between the bark and young wood in plants.

Capsule. The vessel which contains the seed of the plant.

Carbonising. Method of extraction of cotton and vegetable matter from wool by the action of acids.

Carding. One of the early processes in spinning cotton, drawing the fibres through fine wire teeth fixed on rollers revolving at different speeds or upon flats.

Card-room. The room in a mill where the process of preparation by carding is carried on.

Carpel. The leaf forming the pistil of a flower.

Catalysis. The induced chemical action which one substance produces upon another without undergoing change itself.

Celluloid. A substance made by mixing and incorporating nitro-cellulose with camphor.

Cellulose. The chemical substance of which the cell-wall in plants is composed.

Cerosine. Wax prepared from the leaves of the sugar-cane.

Chemicotactic. Directive action resulting from variation in chemical composition.

Chromatophores. Pigment cells contained in the nucleus of a living cell.

Clamping arc. A portion of a circle on the microscope with screw to fix it in any position.

Coarse adjustment. That part of the microscope by which the first focussing of the object-glass on to the object is accomplished.

Collodion. A solution of gun-cotton in ether and alcohol.

Colloid. A substance which will not crystallise.

Combing machine. A machine for selecting the fibres o

cotton of uniform length and cleansing them from mechanical impurities.

Complementary colour. The remaining colours in a beam of light which are necessary to make white light.

Cop. The yarn accumulated on the spindle of a mule or twiner in a conico-cylindrical form, and removed when the spindle is full.

Corolla. The petals of a flower.

Corypha cerifera. The carnauba palm.

Counts. When applied to yarn, means the relative fineness of the thread.

Cross-dyeing. The process of dyeing the warp before weaving and the weft afterwards, or the reverse.

Cuprammonium. A solution of copper oxide in ammonia.

Cytoplasm. The whole of the liquid contents of a living cell.

Crystalloid. A metallic or organic substance which possesses the power of crystallising.

Denticulated. Having teeth like a saw.

Desiccate. To dry up.

Dialyser. A membrane which possesses the power of allowing certain substances in solution to pass through it, while it rejects others in the same solution.

Diameters. When applied to microscopy, signifies the number of times that a linear inch is magnified by the eye-piece and object-glass in use.

Dicotyledon. A plant whose seed is divided into two lobes.

Dhollerah Cotton. A class of East India cotton.

Drawing. In cotton spinning, a process which arranges the fibres in parallel lines by passing them through rollers running at different speeds.

Endochrome. The colouring matter within vegetable cells.

Epidermal layer. The outer layer or skin of a fibre, or other organism.

Eye-piece. The top part of the microscope to which the eye is applied, and which can be removed at pleasure to increase or diminish the magnifying power.

Exogen. A plant which grows by additions made on the outside of the trunk.

Fibrillæ. The strands or minute chain of cells forming secondary deposits.

Fine adjustment. The arrangement by which the final focussing of the object-glass is accomplished in the microscope.

Finishing. The last process to which textile fabrics are subjected, so as to straighten out and improve the surface.

Follicle. A sac-like inversion or involution of the skin.

Germinal cells. Cells in the process of growth, or from which other cells are springing.

Ginning. The mechanical process by which the cotton fibre when ripe is separated from the seed.

Goniometer. An instrument for measuring small angles.

Gun-cotton. Cotton which by steeping in a strong solution of nitro-sulphuric acid has become explosive.

Gymnosperm. The active germs upon which fertilisation depends in plants.

Homogeneous. Possessing one uniform molecular structure throughout.

Hot finishing. The process of forming an artificial gloss upon the surface of goods by the use of hot rollers.

Hydroxyl. The substance produced by the union of a single atom of hydrogen and oxygen.

Hygrometric. Relating to the degree of moisture in the air.

Incinerate. To burn to ashes.

Indigenous. Native to the country.

Inspissated. Dried up.

Inverted pendulum. An instrument for measuring small vibrations.

Kemp. A solid structureless fibre without internal tube.

Kier. A large iron boiler with a false bottom used in the process of bleaching.

Laminated. Built up in layers.

Lanceolate. Pointed at each end.

Laps. Rolls of cotton from which the carding engines are fed.

Leicestershire hog. The first clipping of wool from a Leicestershire sheep.

Leuco-compounds. Bodies which are colourless but which when brought into contact with the oxygen of the air throw down insoluble precipitates which are coloured.

Ligneous. Wood-like—wood fibres in the stem of a plant.

Linear development. Growth in a straight line, not all round.

Lustra-cellulose. Artificial silk fibres made from dissolved nitro-cellulose.

Madder. A plant from whose root the red colouring matter called alizarine was formerly extracted.

Malvaceæ. A natural order of plants, of which the mallow is a type

Mercerising. Subjecting cotton fibres to the action of strong caustic soda.

Metabolic changes. Those which occur in the development of living organisms and which result in the differentiation of the various organs.

Meteorological. Relating to weather and climate.

Micrometer. An instrument for measuring the diameter of very small objects.

Microscope. An instrument for magnifying small objects.

Microtome. An instrument for cutting thin sections.

Millboard. Thick cardboard placed between the folds of cloth during the process of pressing.

Milled head. A screw with the edge or circumference of the head cut into grooves like the edge of a sovereign.

Mohair. The hair from the Angora goat.

Molecule. The smallest portion of any compound substance in which the peculiar chemical properties of the body can inhere.

Monochromatic. Possessing only one colour.

Monocotyledon. A plant whose seed has only one lobe

Monocular. A microscope, with which only one eye can be used at once.

Mordant. A reagent which forms the bond of union between the fibre and colouring matter.

Mule. A machine for spinning yarn, in which the spindles are placed upon a carriage which draws out from the rollers when the yarn is spinning and returns to them when the yarn is being wound on to the cop.

Murexide. A rich purple colour obtained by the action of nitric acid upon uric acid.

Neps. Short immature fibres or portions of tangled broken mature fibre.

Nucleus. The germinating part of an organic cell.

Nucellus. The germinating part of the nucleus.

Object-glass. The small compound lens which first receives the rays of light from the object under examination.

Objective. A short name for the object-glass.

Oleaginous. Of the nature of oil.

Ovary. That part of a plant in which the seeds are contained.

Parachute. The hairy portion of a seed which enables it to be distributed by the action of the wind.

Parapectic acid. A product derived from pectic acid.

Pectic acid. The gelatinous acid formed by the decomposition of pectin, which is found in nearly all vegetable substances.

Pellicle. A thin transparent membrane.

Pistil. The central axis or innermost whorl of a flower.

Pitch of screw. The distance at which the threads of a ..... are apart from each other.

Placenta. The cellular part of the carpel or matrix, to which the ovule is attached.

Plumbic iodide. A combination of lead and iodine.

Plexus. A tangled mass of fibre.

Polarised light. A ray or rays of light, in which all the luminous vibrations are either in one plane or in two planes at right angles to each other. Circular or elliptically polarised light is when the plane or planes of polarisation are rotating round the axis of the ray in a circular or elliptical form.

Polarising prism. An oblique rhomb of crystal used for polarising light.

Pollen. The fertilising dust secreted or generated on the anthers of a flower.

Polysepalous. A seed-vessel having many divisions.

Preparing machinery. Scutching and card-room machinery up to the roving frames.

Protoplasm. The primitive matter which forms the structure of cells and is the physical basis of life.

Reagent. A chemical substance used to act upon another substance as a test of its nature.

Reticulated. Net-like, woven like a net.

Roving. The soft thick thread out of which yarn is spun in a frame or mule.

Rules of thumb. Practical, not theoretical, receipts for any process.

Ruminantia. Animals which chew the cud

Schweitzer's solvent. An ammoniacal solution of oxide of copper.

Secondary deposits. The substance deposited upon the primary cell-wall.

Septem. A thin porous layer between two liquids or gases through which they transfuse.

Sericin. The chemical substance of which silk is formed.

Setting of yarn. Storing yarn in a damp place till the curl is taken out of it, or subjecting it to steam pressure for the same purpose.

Size. A paste of flour, starch, or other stiffening substances, which is used to give strength to yarn previous to weaving, or to give a body to the cloth.

Snarls. Small curled places in yarn.

Spiral structure. Secondary deposits on the outer cell-wall in a spiral form.

Stage. That portion of the microscope upon which the object is placed for examination.

Stamens. The stalks or filaments which carry the pollen-bearing anthers of a flower.

Stereoscope. An optical instrument for two eyes so as to obtain the effect of seeing an object from two angles as in ordinary vision.

Stigma. The summit of the pistil of a flower.

Swift. That part of a wrap reel or reeling machine upon which the yarn is wound so as to form the hank.

Tannin. An astringent substance found in oak and other barks.

Technical. Relation of art to manufactures.

Technologist. One who applies science or art to manufactures

Tester. A machine for testing the strength of yarn.

Textile. Woven fabrics.

Throstle. A spinning frame, with flyer, or ring and traveller, which spins on to a bobbin.

Trinitro-cellulose. Gun-cotton.

Twist-tester. A machine for testing the number of twists or turns in a thread of spun yarn.

Ultimate fibres. The smallest part of an organic structure which can be separated without destroying the organic structure altogether.

Union trade. The trade in mixed fabrics, made usually with a cotton warp and worsted or woollen weft.

Viscoid. A transparent body obtained from viscose by extracting the soda with water.

Viscose. A cellulose compound formed by treating soda-cellulose with carbon-disulphide.

Warp. The yarn which runs in the direction of the length of a piece of goods.

Water of hydration. The water which forms an integral portion of the structure of a body.

Weft. The yarn which runs across the warp from side to side.

Worm-wheel. A toothed wheel driven by the revolution of a screw or worm, into the threads of which it works.

Wrap reel. A machine for winding yarn off cops, or bobbins, or hanks, and measuring the length of the yarn.

Yarn. Fibre when spun into thread.

Yarn-tester. A machine for testing the strength of yarn.

Yarn-tester—Moscrop's automatic. A machine for testing single threads.

Zero. The point on any scale of measurement from which numeration commences.

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THE END

CHAPTER XIII

THEORY OF DYEING

WHILE the mechanical form of the cotton fibre—viz. its length and diameter and the varying differences which are exhibited by the fibres derived from different species of cotton—as has been already seen, influences to a large extent the character of the yarn into which the fibres are made, still this influence is only mechanical. It affects the strength of the yarn and the elasticity, and also the particular character which the yarn possesses, viz. fulness or loftiness, as it is termed, which means that the thread has a larger diameter relatively than the fibres themselves have when taken collectively, arising from the fact that some fibres, such as Surat and coarse Peruvian, have a mechanical structure which resists torsion more than the Egyptian or Sea Island fibres. This results in the yarn being less dense, as the fibres when spun and twisted do not lie so close together, but take wider curves round the central axis of the thread and leave larger spaces between them. They act indeed in the capacity of stiffer springs, which cannot be so closely compressed, and although this property diminishes the strength of the thread with the same amount of twist in it, yet it makes the cloth feel

more full and springy in proportion to the weight, which is an advantage in many cloths.

The mechanical properties of the thread do not, however, influence its relation to the after treatment in regard to dyeing and finishing, except in regard to the capacity which such mechanical arrangement of the molecules in the fibres confers upon it to receive dyes, or to present differences in the character of the reflecting surfaces after they are dyed.

It has also already been seen that the nature of the surface of the fibre greatly influences the lustre of the yarn, because although in the ordinary condition of the fibre the wrinkles and irregularities on the surface are not visible to the naked eye, still, with such processes as mercerising and drying under tension, which smooths out the inequalities, the lustre of the yarn may be greatly increased, arising from the fact that the light is less dispersed. The size of these inequalities, as well as the molecular nature of the cellulose layers composing the fibre wall, which is also mechanical, must and does influence the character of the light which is reflected from the surface, and the impression which it will make upon the eye which receives it.

Limits of Vision. — There is a dispute amongst physiologists and microscopists as to what is the exact cause of the mechanical sensation of light, in its relation to the mechanical structure of the retina of the eye, with its successive layers of rods and cones and ganglia, and as to the theoretical limit of vision, which is known practically to vary in each individual case. Those who have worked with the microscope know how difficult it is to distinctly resolve lines which are ruled more than the $\frac{1}{100,000}$th of an inch apart, or the nineteenth band on Nobart's test

plate, where the lines are 112,000 to the linear inch, and that with the best instruments and best methods of illumination and the use of monochromatic light, the limit of vision is soon reached. The probable limit for ordinary vision is not smaller than the $\frac{1}{150,000}$th of a linear inch, although with an educated eye and proper illumination, and with a high-angled objective, two portions of an object separated by a distance of $\frac{1}{180,000}$th of an inch can be seen. This is, however, enormously larger than the diameter of fluid molecules, or even many solids when precipitated from their solutions by chemical means. Also, as already noticed, no microscopical power reveals to the eye the mechanical texture of the outer sheath or pellicle of the cotton fibre, or even that of the intercellular layer of the fibre. The utmost that can be done so far is to be able to discern the stratification.

Nature of Colour.—It is a common error to suppose that colour is objective, an attribute of the body which appears to the eye as coloured. As a matter of fact it is entirely subjective, as there is really no such thing as colour as an attribute of any substance. The sense of colour is entirely derived from the nature of the undulations of the all-pervading luminiferous ether which are returned by radiation from the surface of the body, which appears as coloured, and in which the length of the undulating wave determines the specific character of the colour, and the amplitude of the undulations its intensity. The reason why bodies, therefore, appear to be different in colour is because the surface has a specific molecular structure, which enables it to radiate undulations of a specific wave-length and corresponding amplitude, and all dyeing processes are only a method of giving a new reflecting surface to the substance, so as to enable it to select a specific order of radiations

from the polychromatic rays of light which fall upon it, and reflect only these to the eye while absorbing the rest. Sunlight is composed of an almost infinite number of differing wave-lengths, which when they fall all together on the retina of the eye give the sensation of white light, and when none are present the sensation of black, which is only the absence of any rays. If the light from the sun is passed in a particular direction through a prism of glass or other refracting material, or permitted to fall upon a surface which is ruled with a series of very fine parallel lines, at right angles to these lines there is produced an almost continuous band of colour, which is termed the solar spectrum, in which the various colours always stand in the same relative order, which is determined by the wave-length and the number of undulations per second. This is the same order as they appear in the rainbow, in which the sequence is always—violet, indigo, blue, green, yellow, orange, and red; the violet rays being those which are most refracted or bent out of the straight line on passing through the prism, and the red rays the least. The nature of the solid or liquid medium forming the prism also affects the degree of this bending, because some substances have greater refractive power than others, which depends upon the relation between their molecular structure and that of the wave-length of the vibrations passed through them; and also in the non-transparent substances the power of reflection from the surface depends on the degree of penetration of the rays, within the surface, before reflection, and which may be termed surface transparency. We have already seen that the lustre of cotton depends upon the reflection of light from the plane surfaces of the collapsed tubes; and wherever these plane surfaces are broken up or wrinkled, either by mechanical or chemical

means, the light is dispersed in every direction, instead of being reflected in a sheet to the eye, like light from the surface of still water, and the fibre then looks dull and not silvery.

There is also a great difference in the transparency of the fibres of different cottons, which arises from the specific differences in the methods in which the cellulose layers in the cell-walls are arranged, and which will be easily seen by the use of polarised light. This difference the author has found to have a remarkable effect upon the power of the fibres to receive bright colour in dyeing, as it evidently determines the depth of light-penetration within the surface of the fibre, and varies the relation between the amount of light returned by internal and purely surface reflection, which are usually of two different orders, as may be clearly seen by analysing the rays thrown off from the surface, at right angles or any other angle, with a spectroscope.

In the case of examining single fibres, when dyed, it seems generally that a large part of the colour is derived from internal reflection, although undoubtedly there is also reflection from the surface of each speck or flake of dyed material which lies in successive layers of the cellular walls, which, however fine the division of these flakes, act as reflecting surfaces like motes in dusty air, reflecting sunlight to the eye. When, however, the fibres are associated in a thread, forming a twisted strand, there is always a comparatively large quantity of colouring matter associated with the fibres and lodging in the spaces between the fibres occasioned by the twist in the yarn, and which can never be entirely removed by washing, and from these surfaces the largest part of the coloured light is reflected, to some extent modified by the internal reflection from the surface

fibres of the thread and the angle at which the light is reflected, which determines the amount of white light with which the coloured light is associated when it reaches the eye.

Polychromatic Light.—The colour which a body will appear to be depends, therefore, upon two functions and not one. The first is the nature of the surface itself, and the second the character of the light which falls upon it. When the molecular structure of the surface of the body is such that when white light, which is a mixture of all wave-lengths, falls upon it, it will suppress all undulations but those of one definite wave-length, and return these alone to the eye, there is a pure monochromatic colour, whether yellow or blue or red, or whatever it may be, depending on the molecular structure of the surface. It will, however, depend on the nature of the light also, because if the light which is falling upon it does not possess the wave-lengths which it is best fitted to reflect, or if they are few in number, the colour will appear dim and unsatisfactory. From physical causes, connected with the nature of the atmosphere of the sun and earth, the rays of white light received from the sun do not contain every wave-length, and some colours are therefore absent, and the spectrum of the sun, when examined through a prism by the aid of a spectroscope, shows a disruptive and not continuous spectrum, the rays and colours which these absent rays would give being represented by dark spaces known as Fraunhofer's lines, from the name of their discoverer. All colours, therefore, are not to be found in sunlight, and this limitation is also much more marked in many artificial lights, such as gaslight, and this is the reason why the same goods look different colours and shades in sunlight and gaslight. This is also the reason why the matching

of shades can only be done in sunlight, and even then in diffused sunlight, and not in bright light. All colours visible to the eye are found in the electric arc, or the oxyhydrogen light, or in many incandescent burners depending on the temperature and nature of the radiating surface, which greatly influences the proportion of the colours, and hence the peculiar effect produced on the eye when coloured bodies are seen with these various sources of illumination.

Monochromatic Light.—If the light under which a body is seen only possesses in it one set of rays, or is a monochromatic or one-coloured light, then all bodies, however varied in colour when seen in ordinary daylight, cease to have any distinction except being darker or light varieties of the same shade. This may easily be proved by viewing a box of various shades and colours of silk ribbon, or a pattern-book of dyers' colours, or a set of wall papers by means of a flame of alcohol impregnated with common salt, which gives off only the characteristic yellow light represented by the D lines in the solar spectrum, which are in the brightest portion of the yellow band. With this light alone it is impossible to tell any of the colours from the others, however distinct when seen under ordinary daylight, all colours, from the brightest red and blue and green, only appearing as various shades of a yellowish grey. The entire absence of red rays gives the face of the observer the appearance of that of a corpse, and the look of the eyes is very singular.

In practice, and with sunlight, or even artificial light, a perfectly monochromatic light is impossible, and the light which is reflected from any body will always, when examined with a spectroscope, give a band which has an appreciable width, showing it is composed of rays of

different degrees of refrangibility, if not, as in many cases, a discontinuous or disrupted band, which shows a more varied refrangibility in the rays and a less degree of monochromatism.

Nature of Dyeing.—The object of dyeing is, therefore, simply the production on or within the surface to be dyed, whether it is a fibre, or a thread, or a piece of cloth, or any other material, of such a molecular condition as will reflect certain luminous wave-lengths, whether by internal or surface reflection, and suppress or destroy by neutralisation others. This, it has been found, can be accomplished in many ways, the means employed being varied to suit the different substances which have to be dyed, and their physical condition at the time.

Conditions of Dyeing.—Perfect dyeing must fulfil the following conditions, and must result in—

1. Cleanness and distinctness of colour, whether it is a full or half shade which may be desired, so that the rays of light reflected from the surface may be as far as possible all of one kind, or of such an association of kinds as will give the same uniform sensation to the eye.

2. Permanence or fixity of colour, so that the reflecting character of the new surface will remain unchanged, and will not, therefore, even after a time, alter its molecular structure so as to vary the character of the rays which are reflected, and so alter the colour or shade which was originally given to it. Of these two conditions the latter is far the most difficult to attain, and specially in mixed fabrics, when more than one material is employed, such as mixtures of cotton and wool and silk and other fibres, because it is far more difficult to produce the same shade in one than in the other, and often entirely different means have to be employed. It may be said indeed that no dye

is perfectly permanent, but fades or changes to some extent under the varying conditions to which it is subjected in use.

Importance of Investigation.—Investigation as to the nature of the dyeing process should take into account the differing chemical constituents of the cotton fibres, in different seasons and under varying conditions of ripeness, for it is evident, from what has already been seen, that these substances must be factors in the process to which the fibres will be subjected in the dyeing, if the process is to be scientifically conducted. It is quite evident the cotton, which is one element, and that which it is proposed to colour, does vary greatly in both mechanical and chemical characteristics, and that in practice this must influence the action of any other materials with which it is necessary to bring it into contact, and that if there is action there must also be reaction, the nature of which is of the highest importance to the technologist to understand, so that he may modify his process to suit both the material and the dye, the mutual action of which must necessarily be reciprocal if the process is a chemical one.

Simple and Compound Dyeing.—Although dyeing seems to the uninitiated to be a simple process, it is by no means so. There is a great difference in the quality of colour as well as the shade or colour itself, and this depends not only on the intensity of the surface coloration but upon the method of reflection also. Just as in music the same note has a different quality if sounded on a brass or wood instrument, a different "timbre," as it is called, so the quality of the colour on any fabric depends upon the nature of the colouring matter and the surface which is dyed. The same colouring matter does not give the same quality of colouring upon mercerised and unmercerised

can be dyed with simple colours, that is, with a monochromatic dye, the quality of the same kind of colour can be improved and heightened by the use of compound dyeing, in which more than one colour is employed to attain the desired shade. This arises from the fact that none of the colours at our disposal are perfectly homogeneous, but are the result of compound reflections, and if analysed with the spectroscope are found not to consist of a simple band of colour.

In dyeing textile fibres, therefore, most of the colours are produced by combining together several dyes, "mode" colours being, as a rule, generally obtained by combining together yellow, red, and blue, the character of the dyestuffs being such as will mix together and possess good equalising properties, that is, even distribution throughout the fabric without cloudiness. Care has, therefore, to be taken to select the dyes to be used from such classes as will work well together, and these are generally found in the same group, whose affinities are similar.

Theory of Dyeing.—The rationale or theory why and how the desired reflecting surface is obtained by what we ordinarily call the fixation of colour upon various fibres or fabrics is a matter of doubt and controversy, even to the greatest authorities, at the present time. It was supposed at one time by some chemists that between the colouring matter and the fibre there is a true chemical combination, and that the change occurs in equivalent proportions. Others believe that the combination arises from a special action, in which the usual chemical equivalent proportions do not obtain, being modified by the catalytic action of the fibre. Others are of opinion that chemical action has little to do with the matter, and that colours are fixed upon or within the surface of the bodies by molecular

attraction alone, while some again think that the action is altogether mechanical, and that the colouring matter is absorbed into the pores and cells of the fibre, and held there simply as a pigment might be enclosed in a glass bottle.

Summary of Theories.—These various opinions may be arranged under three heads, and summarised as follows:—

1. That the fixation of colouring matter, however produced, is accomplished by an affinity or attraction between the colouring matter and the fibres in the same manner, but differing in degree from the ordinary chemical combination which occurs between unlike chemical bodies in which an insoluble colour or "lake" is produced.

2. That the fixation of colour does not depend entirely upon any chemical affinity which may pertain between the fibres and the colouring matter, but also upon the mechanical structure of the fibres or fabric, which by absorption, within the structure of these, fixes the colour and forms a reflecting surface, the degree of fixity depending on the nature of the colouring matters themselves, as well as on the degree of mechanical stability within the fibrous structure itself.

3. That there is no chemical relation or reaction between the fibres or fabric and the colouring matter, but that the successive layers or walls of the fibres simply form so many envelopes within which the dye-stuff is deposited, and that the colour is entirely dependent upon the nature of these colouring matters themselves, which form the reflecting surface, and the permanency or stability of the colour upon the degree of permanency in the colouring matters, and the amount of mechanical shielding which the structure of the fibres or fabrics yield to them.

Chemical Theory of Dyeing.—The first of these

theories may be considered as a purely chemical one, in which the production of a dyed surface is the direct result of a reaction between the substance of the fibre, that is, the materials composing it, and the materials of the various dye-stuffs, and this theory was strongly advocated in the last century by Bergmann, Macquer, Persoz, and Chevreul, and in the century before by Dufray, and there is much to be said in its favour, since it is quite clear that if all the various changes which occur in dyeing are the result of ordinary chemical reactions which are within the control of the chemist, the power to act is at once put upon a satisfactory basis.

There is no doubt that the evidence for a purely chemical theory is much stronger in regard to the dyeing of animal fibres, such as wool and silk, than in the case of cotton and the cellulose fibres generally, because the latter are far more chemically inert, and possibly a larger share of the reactive effect must be put down to the unchanged or incompletely changed cell-contents within these fibres than has usually been considered due to them. It has already been seen that true chemical compounds are formed with pure cellulose, and that it is particularly open to changes by hydrolysis, which render it more amenable to chemical reaction when it is brought into contact with either acids or alkalies, and these are just the changes to which it is subjected in dyeing, quite apart from any unchanged cell-contents which may be associated with it, and it is these changes, as in the case of mercerising, which largely increase the capacity of the fibre both in regard to its absorbent qualities and the amount of colouring matter which it can retain when subjected to subsequent washing.

In the case of cotton, which may be regarded as a hydroxyl compound, it will necessarily possess acid rather

than alkaline properties, and this is in accordance with what is found to be the case if there is a chemical reaction in the dyeing process, viz. it dyes best, and is therefore usually dyed, in an alkaline or neutral and not an acid bath, which seems to indicate that the opposite affinities of acid and alkali have a part in the reaction.

In the case of wool, which is a much more complicated substance chemically, and which contains as a part of its composition bodies which are both acid and alkaline, there is no doubt whatever that the reaction is chemical, as, for instance, when it is dyed with a colourless solution of rosaniline base the wool itself is dyed as with magenta, or when dyed with solutions of the hydrochlorides of basic coal-tar colours the salt, according to Prof. Knecht, is decomposed by the wool acting as an acid, which decomposes the salt, and after combining with the base leaves the whole of the hydrochloric acid in the solution. The same characteristic action is also observed in the mordanting of wool, where in some cases it absorbs and fixes the basic elements in the mordanting bath, and leaves an excess of acid behind.

The great difference in the complexity of the molecule in cotton, silk, and wool may be seen by looking at the typical formulæ for the composition of each :—

Cotton (cellulose) $C_6H_{10}O_5$
Silk (cerocine) . $C_{24}H_{38}N_8O_8$
Wool . . $C_{42}H_{157}N_5SO_{15}+P$

which is an albumo-proteid-gelatinous body.

The second theory may be termed the

Chemico-mechanical theory of dyeing, because it recognises that the power to receive and to retain the dye-stuff depends not only upon the chemical constituents of the fibres and their chemical association at the time, but

also upon their mechanical structure, and that for a full and correct knowledge of any dyeing operation it is as necessary to study the physics as the chemistry of the reaction.

Modern research is indeed continually tending to narrow the dividing line between all the different branches into which scientific knowledge has hitherto been classed, and to consider all changes which matter undergoes, and the means by which these changes are effected, as purely physical, and that both are subject to the same laws of mass and dynamics, modified only by the distances at which they act, the nature of the conditions, and stability of their motions. These laws must necessarily be varied, when it is remembered that in the great majority of cases both the substance to be dyed and the dyeing materials are put under conditions in regard to temperature and moisture, as well as one of them being in solution, which are eminently favourable to determining change in each, and that care has always to be taken to prevent the physical properties of the material to be dyed, such as strength and flexibility and lustre, being in any way altered, and therefore that this mechanical texture must act both in regard to capillary action and molecular entanglement upon the dyeing solution, exactly the same as if it was only a fluid possessing the same physical properties. This theory is probably the one which is now the most universally accepted, and which may be said in most cases to give the most rational explanation of the phenomena, and will account for the action of both simple and complex dyes.

The third view, which is a purely

Mechanical theory of dyeing, was advocated during the last century by Hellot and Le Pileur d'Apligny, who may indeed be said to have been its authors, and was

powerfully supported by Walter Crum, in his researches on the dyeing of cotton, specially in regard to the production of Turkey red. Witt's theory (*Jour. Soc. Dyers and Col.*, 1890, p. 173) partially supports this view by considering the substance of the fibre as more or less solid solvents, which extract the colouring matter from the dyeing solution, just in the same way that ether will extract resorcin from its aqueous solution when shaken up with it.

Amongst other points Crum bases the theory of purely mechanical action upon the following phenomena, and says: "If we only consider that chemical action necessarily involves combination, atom to atom, and consequently disorganisation of all vegetable structure, and that cotton may be dyed without injury to its fibre, and that the fibre remains entire when by chemical means its colour has again been removed, we shall find that the union of cotton with its colouring matter must be accounted for by otherwise than by chemical affinity."

It will be seen that this theory fixes the attention almost exclusively upon the completely transformed cell-contents, and does not take any account of the more active and unchanged elements, and regards the cellulose layers as simply absorbing membranes which act as dialysers under the ordinary laws of endosmotic and exosmotic action, and no doubt this is to a large extent true in regard to the action of adjective dyes, the colouring matter of which may be regarded as precipitates within the fibre walls in which lakes are formed. This also was the view taken by Müller Jacobs,[1] who regards all dyeing processes as entirely based upon these actions.

Perhaps the best general theory of dyeing is that

[1] *Textile Colourist*, 1885, and *Journal Soc. Dyers and Col.*, 1885-86.

advanced by the eminent Frenchman M. Chevreul, who after giving a lifetime to the subject summed up the results of what he believed to be the action in dyeing as:

1. By chemical affinity.
2. By simple mixture with the fibres.
3. By being in both states at once.

By the latter statement he evidently did not mean that the same matter is in both states at one and the same time, but that there are cases where the colour of the fibre is partly due to the union of the colouring matter with the fibre, and partly to the presence of the same colouring matter in a state of mechanical mixture with the material forming the cells of the fibre.

Probably, indeed, no general theory of dyeing can be formed which will include all cases and all classes of fibre until there is a much wider knowledge, based upon careful experimental research in many individual cases, and which alone can form the basis for any extended generalisation.

It must be also remembered that in every dyeing process the results are dependent upon two functions and not one,—there is the fibre to be dyed, but there is also the dye to dye it, and the nature and action of this dyeing material, whether it is derived from mineral, vegetable, or animal sources, or produced artificially, cannot be left out of account when studying the phenomena. As these dye-stuffs differ in their origin they also differ in their character, and their classification may be based therefore upon various methods, depending upon the standpoint from which they are viewed, as, for instance, their origin, in which case they may be divided into two principal groups:—

1. **Natural dyes**, which are mostly the products of organic life, such as coloured vegetable infusions and extracts. These do not, however, usually exist in the plants

as coloured bodies, but as potential colouring matter, or chromogens, as they have been termed, because they must undergo a process of fermentation and oxidation in order to become coloured, as in the notable case of indigo.

2. **Artificial dyes**, which are the products of chemical synthesis, such as most of the coal-tar products, and which, as the science of organic chemistry becomes more fully known, seem destined to supersede all the others, as in the case of artificial indigo and alizarine, which have substantially replaced natural indigo and madder.

Viewed in relation to their action, Bancroft, in his *Treatise on Permanent Colour*, written at the beginning of the last century, divided them also into two classes.

1. **Substantive dyes**, or those dyes which will dye the fibre directly and without the intervention of any mordant or fixing agent, such as indigo extract, chrysophenin, or benzopurpurin.

2. **Adjective dyes**, which will only dye the fibres when they are treated or mordanted with a metallic salt or oxide, which, when added to the dyeing bath, or where the fibres have been previously treated with it, fix the colour upon and within the fibre in a permanent form, as, for example, logwood, alizarine, cochineal, and fustic, which when used along with iron, alumina, chromium, tin, etc., produce intensely coloured lakes within the substance of the fibres which are quite fixed and permanent.

In some cases the dye-stuff only yields one class of colour, whatever mordant may be used, whereas others yield a series of colours where different mordants are employed, and the former class, amongst which may be named magenta, orchil, indigo, etc., have been termed mono- or autogenetic dyes, while the latter, which are mostly adjective dyes, like those named above, have been termed

polygenetic. This is the classification adopted by Hummel in his work on the *Dyeing of Textile Fabrics* (p. 147).

A third method of classification may also be adopted which is based upon neither the origin nor constitution of the dyeing materials, but upon their method of action—that is to say, the means or method which has to be employed to bring them into union with the fibres.

1. Acid dyes.
2. Basic or tannin dyes.
3. Substantive or direct cotton dyes.
4. Mordant dyes.
5. Vat dyes.
6. Dyes formed or developed on the fibre.
7. Sulphide dyes.

It has already been seen that so far as cotton is concerned its relation to any dye-stuffs is much more passive than that of either wool or silk, and that most of the dyeing operations are conducted in a neutral or alkaline and not an acid bath, and in their relation to cotton, dyes may be said to be of three kinds.

1. Those which are coloured in themselves, and which may be termed simple dyes, having a direct affinity for the fibre without the intervention of a mordant, such as turmeric yellow, and the whole series of artificial direct dyes, such as Congo, benzadine, diamine, etc. dyes.

2. Those which are true chemical precipitates formed within the walls of the fibre, in which the action of the fibre seems to be purely mechanical, of which such colours as Prussian blue, indigo blue, etc., and chrome yellow are examples.

3. Those where a mordant is necessary, and the colour is not produced by the simple union of the fibre with the colouring matter, nor by the formation of lakes within the

meshes of the fibre, but by the union of the mordant with the fibre and the reaction of the mordanted fibre and the dyeing material, of which the most important are Turkey red, several catechu dyes, and in a secondary degree logwood black and all the tannin dyes.

Although these threefold methods of action of the dye-stuffs in relation to the materials to be dyed seem to indicate considerable differences in the method of operation, still, a careful examination of the nature of the classified dye-stuffs seems to indicate that the mutual relations of the members of each class, in regard to the fibres and to themselves, depend more upon a single property held by them in common than upon their actual composition. This appears to be, their acid or basic qualities, or, in cases where both, as resulting from the composition of the dye-stuff, are present, upon the relative balance of the two.

General Relation of Dyeing Materials.—Thus all the acid dyes, whatever may be the specific character of their acid properties, and from whatever acid derived, behave in regard to the fibres to which they are applied in a similar manner, because the acid property is generally due to the presence of sulpho-, nitro-, and hydroxyl groups in their composition, of which the last are usually the most active, and their action seems to indicate only differences in degree and not in kind.

In the same way all basic dye-stuffs, whether azo-compounds such as chrysoidine, or triphenylmethane derivatives such as magenta, as a consequence of one or more amido groups which are present in each, and upon which their basic action depends, exhibit more or less the same pigmentary character.

All the substantive dyes indeed, in this relation,

contain more or less basic and acid groups in their composition, and are thus able to react without the aid of a mordant upon any fibre or other material which contains in itself either of these properties, and in their relation to the dyeing of cotton it is quite clear that it is the basic constituents in the dyes which react with the hydroxyl groups in the cellulose. With regard to cotton dyeing the same remark also applies to adjective or mordant dyes, in which the reaction evidently not only depends upon the acid character of the hydroxyl groups, but also upon the nature and arrangement of the groups themselves within the cellulose molecule. If this was not the case the capacity of a dye for fixing with mordants would be increased and not diminished by the presence of strongly acid sulpho-groups, which is not the case.

With these general remarks it is now possible to consider the general principles of the relation between the dyeing process and the mechanical structure of the fibres to be dyed.

Process of Dyeing.—Whatever the nature of the fabric to be dyed, or of the dye-stuff to be used, the universal practice is to present the dyeing materials to the fibre or fabric dissolved in water or other menstruum either cold or hot. The dyeing process arises from the absorption of the dyeing material in solution into the substance of the fibre.

From whatever cause this action arises, the absorption always proceeds in one manner, viz. the dye is absorbed more rapidly at first and gradually diminishes until a point is reached where no more will be withdrawn from the solution, however long the material to be dyed is retained in the bath. This action may be represented graphically by means of a curve drawn upon a chart, in

which one dimension represents time, and the other the quantity or percentage of material withdrawn from the solution. This curve differs for every material, and generally for every class of dye-stuff. In most cases the absorbent action is increased by raising the temperature of the dye bath up to the boiling point. There are cases in which, if the quantity of dye is small in proportion to the quantity of material to be dyed, the whole of the colouring matter will be extracted from the solution. As a rule, however, a portion of the dye always remains in the bath.

There is a point, however, reached, in the case of all fibres, in which a maximum of effect is attained and beyond which no further absorption takes place, and it must be specially noted that the first portions of the dye, which are absorbed the most rapidly, are always the most permanent and fixed, on and within the fibres, which seems to indicate that in some way the power to absorb decreases the longer it is exercised, as if either the affinities become saturated or some other mechanical change occurs which hinders the absorption by filling up the pores. It is found also that all fibres absorb relatively more dye in proportion from dilute than concentrated solutions, and that under these circumstances the attachment of the dye to the fibre is more fixed. Whenever dye-stuff has been absorbed by a fibre it can never be again entirely removed by washing with cold or hot water, even if the dye is completely soluble in water, which shows that the dye, although it has undergone no change in chemical composition, has in some manner changed in regard to the solvent by its absorption into the texture of the fibre. That the characteristics of the dye within the fibre are unchanged can be proved by the reaction being with other bodies exactly the

same as possessed by the dye-stuff itself with the same bodies outside the fibre. Thus dyes containing a free amido group can be diazotised on and within the fibre, and converted into more complex azo dyes by coupling with phenols and amines; and very dark dyeings with magenta, methyl violet, and similar dyes will bronze exactly the same as outside the fibre. The dyed fibre behaves in all respects like a salt of the dye-stuff.

It has also been found that where more than one dyeing material is used in treating a fibre or fabric the absorption exercised in the case of one is quite independent of the others, or of the order in which they may be made to come into action, so that since their action is quite separate it is immaterial whether they are made to act successively or at one and the same time. Care must also be taken that they are not of such a character that they react with each other, and so either form a new combination, which is soluble in the solution, in which case the new substance would act independently, or cause a precipitate, in which case they would be removed out of the solution and so entirely cease to act. There may, it is true, be a difference in the time element between them, but in any case it is necessary that the material to be dyed shall remain in the solution sufficiently long to enable equilibrium to be established in regard to the distribution of the dye between the fibre and the dyeing solution.

Georgievics (*Chemical Technology*, 1902, p. 132) suggests that this relation between the definite absorption of the fibre and the quantity of dye absorbed in relation to the quantity remaining in the dye bath, after the saturation of the fibre by the dye is complete, points to a general law, according to which our dyeing processes should be conducted.

Law of Distribution.—In regard to this he remarks as follows:—

"This behaviour of dye-stuffs in dyeing must be based on some definite law, which may be ascertained by the quantitative examination of the distribution of a dye between the fibre and the bath.

"By determining how much dye has been taken up by the fibre, and how much is left in the bath, and calculating, from these data, what quantities of dye are contained in equal weights of the fibre and the bath liquor, we obtain two values which may be expressed as Cf (fibres) and Cb (bath). The quotient $Cf \div Cb$ is termed the coefficient of distribution, and its dimensions depend on the nature of the dye-stuff and fibre, the temperature of the dyeing process, and the concentration of the bath liquor in relation to the amount of fibre treated. The rule is, that the coefficient of distribution slowly sinks as the concentration of the bath increases. If this diminution of the coefficient be actually quite uniform, then, for mathematical reasons, the expression $\sqrt[x]{\frac{Cb}{Cf}}$ must possess a constant value independent of the concentration. This is, in fact, actually the case in two instances, viz. the dyeing of silk with indigo carmine at boiling heat, and the dyeing of mercerised cotton with methylene blue in the cold.

"When it is considered how varied are the circumstances and factors coming into play in these two dyeings, and that a gradual reduction in the coefficient of distribution is also noticed in numerous other instances, there will be no hesitation in according the above expression the dignity of a law, which, however, for reasons which cannot be argued out in detail here, only applies in its full extent to light medium colours. The aforesaid peculiarities of

the dyeing process find their precise mathematical expression in the formula,

$$\sqrt[x]{\frac{Cb}{Cf}} = \text{K, which is a constant.}$$

"This is the law of distribution, and from this it will be seen that the value of the root sign x affords a measure of the affinity of the dye for the fibre, and naturally varies for different dyeings, being greater in proportion as the affinity of the dye-stuff for the fibre increases.

"From this law follows the practically important fact that the absorption of the dye, specially those that are not taken up readily, is primarily dependent on the volume of the bath liquor. It would, therefore, be more correct to apportion the weight of the dye taken to the volume of the bath liquor, and not, as is usually the practice, to the weight of the goods to be dyed."

Although this law undoubtedly holds good in some case, there are a number of cases in which it does not express the relation, and it cannot therefore be taken as of universal application.

For perfect dyeing, in addition to the proportion of the dyeing materials being correctly co-ordinated to the material to be dyed, it is also requisite that the material shall possess the necessary receptivity, and that it shall be prepared in such a manner that this quality shall be placed in the best condition to receive the dyeing material. The means by which this can be accomplished must therefore receive attention.

CHAPTER XIV

RELATION OF THE COTTON FIBRE TO THE DYEING PROCESS

In dealing with the question of the relation of the cotton fibre to the process of dyeing it is well to remember that although the base and by far the largest portion of the fibre is cellulose, this is always associated with more or less unchanged cell-contents, which have an entirely different chemical composition, and with oils, fats, and waxes, which, although chemically inert, exercise a considerable mechanical influence by coating the cellulose constituents on the external surface, and also cementing the successive layers of the envelope, as well as filling up the pores of the cellular structure, and so hermetically sealing them against the entrance of any liquid, without the absorption of which into the interior any dyeing process is rendered impossible except surface dyeing, as in the case of artificial silk, although in this case, as there are no oils or fats present, a certain degree of absorption takes place.

Effect of the Structure on Dyeing.—The mechanical condition of the fibres at the time of dyeing may indeed be considered as the most important factor in the obtaining of satisfactory results, because the prime function in the

raw material to be dyed must be its receptivity in regard to the dye, and its mechanical structure determines this. This receptivity does not arise from the nature of the material itself, because the same material, if in a different state, acts mechanically differently in regard to dyeing. Thus amorphous cellulose or cellulose in powder, although chemically the same, will take up a larger proportion of the dye from the dye bath in the cold than when in the fibrous form, a result which probably arises from the greater surface presented by the colloid or powder. In the warm dye bath the conditions are reversed, and, while the fibrous structure of the raw material offers a greater resistance to the extraction of the dye from the dye bath, the fibres possess a greater retentive property, and the dyeing is faster and more permanent.

The importance of the structure can be best proved by dyeing in two states any material with a substantive dye, which possesses only slight affinity for them, and noting the result. Thus a neutral body such as asbestos, when dyed in the fibrous condition, takes up and retains a fair amount of the dye-stuff, while in the state of powder it absorbs very little.

There is also no doubt that, with a structural and not an amorphous condition of matter, new laws come into operation as assistants to the distribution of the dye-stuff between the dyeing material and the dye bath, such as those of osmotic action and capillarity, as a consequence of which, although they do not set aside the law of distribution, they alter to some extent the nature of the constant K, in which case we have—

$$\sqrt[x]{\frac{Cb}{Cf}} = \text{K, a variable,}$$

the degree of variation depending upon the physical condition of the material to be dyed.

Law of Equalisation.—When material to be dyed is brought into contact with dye-stuff, the action which occurs tends to bring about, and, if undisturbed, does finally bring about, a state of equilibrium between the amount absorbed by the material and the amount which remains in the dye bath depending upon the nature of the materials and their respective affinities. This holds good not only in regard to the whole of them taken collectively, but also upon the variations in the absorptive power of the different parts of the material, which, unless the material is mechanically homogeneous, will interfere with the even distribution of the colouring matter in the fibre. This is quite noticeable where dyed fibres are examined under the microscope, as will be seen hereafter.

Reversibility of the Dyeing Process.—The process of dyeing is to a certain extent reversible, that is to say, if material dyed with direct cotton colours, and especially when undried, is placed in a bath which does not contain dye-stuff but only the same solvent which was used for the dye, and which is generally water, a portion of the dye will be extracted, but never the whole, the amount being dependent on the two functions of nature of structure, and affinity. This action takes place in every dye bath, even when the solvent contains the dyeing material in solution, so that unless other conditions come into operation which affect the attainment of equilibrium in the parts, such as the presence of mechanical or chemical impurities, there is a constant tendency to effect even distribution by the transference of the colouring matter from one part of the fibre to the other, until even distribution is attained. This is specially the case with substantive dyes, but is also equally

true, but to a lesser degree, in adjective dyes, and the action is greatly promoted by the agitation which is usually given both to the material and the dye during the dyeing operation.

Although the nature of a dye is not changed when associated with the fibre, and its action remains exactly the same with or without the fibre, still, the molecular condition or state is changed, and the molecular character of this change depends not only upon the nature of the dye but also upon the nature of the fibre. Hence some dyes which are quite fast both to washing and light on some fibres are fugitive on others.

Fastness to Washing.—In regard to fastness to washing the structure of the fibre plays an important part both in relation to its mechanical and chemical composition. Whenever the dyeing materials tend to form precipitates either with the unchanged cell-contents or with a mordant previously fixed on to and within the fibre, the fastness depends upon the fixity of the colour in regard to its solubility in alkaline or acid solutions, and this remains exactly the same as would be the case even if the fibre were not present; but when the action forms insoluble compounds, and specially where these are also partially or wholly occasioned by a chemical action between the actual substance of the fibre and dyeing material, so that they are not only mechanically entangled within the meshes of the fibre, and so shielded from mechanical abrasion, but also in chemical union, so that any solvent has to overcome the affinity of the fibre, the highest degree of stability is attained. Often, too, the most serious causes of want of fastness are dependent not upon solvents but upon gaseous action, such as oxidation by the air, which, with certain dye-stuffs, causes soluble compounds to be

formed, or when not soluble, colourless compounds. Witt was of opinion that much of the fastness of colour was dependent upon an actual solution of the dye-stuff in the fibre, in the same way that oxides are soluble in precious stones (*Farb. Zeit.* ii. 1-6), and indeed that most of our dyeing processes are dependent on solid solution. There is no doubt whatever that the mechanical condition of the dyed material or fibre does largely influence the fastness to washing, because with the same dye and the same method of dyeing the colour is much faster on any fibre than on the same material when dyed in an amorphous condition.

Fastness to Light.—That colours do change under the action of light, and that in some fibres the same colour is more readily changed, which can only be accounted for by some action on the part of the fibre, has long been known. The cause of this appears to be that the same dye may be absorbed in varying molecular dimensions by different fibres, and the change is therefore due, not to the fibre, except in so far as it conditions the state of the dye, but to the nature of the dye-stuff. In this respect the action of the dye in regard to light is the same as in regard to fastness to washing—it is quite independent of association with the fibre. The action of light upon inorganic salts is well known, and is the basis of photography, but that of light upon organic substances has received attention to a much less extent, and it seems to produce change in the character of the substance, either by a direct rearrangement in the molecule itself, as when benzophenone dissolved in alcohol is reduced to benzpinacone and aldehyde, or the aromatic nitrobenzaldehyde is changed into nitrobenzoic acid, as indicated in the following reaction:—

$$
\begin{array}{ccccc}
 & CHO & & & COOH \\
 & / & & & / \\
C_6H_4 & & \rightarrow & C_6H_4 & \\
 & \backslash & & & \backslash \\
 & NO_2 & & & NO
\end{array}
$$

Nitrobenzaldehyde. Nitrobenzoic acid.

or a change which is probably equivalent to polymerisation, as in the polymerisation of formaldehyde, in which we have the same percentage composition but a change in molecular arrangement.

Ageing.—In cases where the products are all coloured the action may simply be temporary and reversible, so that the colour may be restored by the fabric being left for some time in the dark, but in other cases the action is equivalent to a permanent bleaching action, as was formerly so noticeable in mauve and many of the earlier coal-tar products. The fastness of the dye, both to washing and light, also is considerably increased by what is termed "ageing." This process is specially employed where mordants require to be used, and consists in permitting the dyed fabric while in the damp state to remain for some time in the presence of air and moisture. This period of rest enables either the mordant, or in the case of some dyes, the dye itself, to distribute itself evenly through the whole of the fibre, so that it is much more even as well as fast. It seems, therefore, that from whatever standpoint the relation of the fibre to the dye-stuff may be viewed, there is strong evidence to believe that the action is really physico-chemical, and the preponderating influence as to whether the action shall be greater physically or chemically depends upon the nature of the fibre. Experiments made by the author led him strongly to believe that in wool and silk the chemical action is the preponderating factor, and the far more complicated

chemical composition of these fibres as compared with cotton renders this extremely probable.

It is also well known that while most colours are faster upon wool and silk than cotton, and more difficult to remove, indigo, which is deposited within the fibre from its soluble condition by the absorption of oxygen, is faster upon cotton, which indicates that in regard to the cotton fibre the preponderating influence is mechanical.

Penetration of Dyeing Materials.—This opinion is further strengthened by the fact that cellulose when precipitated from its solution in cuprammonium can be mordanted and dyed in exactly the same way as when in its fibrous condition; indeed, that in this state in proportion to its weight it takes up a larger quantity of dye-stuff than would be the case with the fibre alone, and further, it exhausts the dye bath more completely, showing that the preponderating influence is on the side of the cellulose. A microscopical examination of this amorphous mass, however, shows a great difference in the method in which the colouring matter is associated, as compared with the disposition of the colour in the fibre. In the jelly it is diffused through the whole mass in such a manner that it is equally coloured all through and in every part, while in the cotton fibre, unless specially prepared, it is always more or less cloudy or ununiform, and always resolvable into flakes, with a sufficiently high microscopical power and proper illumination. If the union between the cotton fibre and the dye-stuff was purely chemical, it seems to stand to reason that, as a rule, the colour would be more deeply seated in the texture of the fibre, as the power of chemical affinity is far more tremendous than that of mere mechanical action, and also that the depth of penetration into the

substance of the fibre would be greater than it is always observed to be.

While the colouring matter, as such, does not appear to penetrate the fibre, and possibly this may be accounted for by the fact that it must be solid matter in a particular condition of molecular aggregation before it can reflect colour, a mordant which is colourless has great penetrative power, even when the conditions are not favourable to liquid diffusion.

All dyeing is accomplished by a wet process, and some writers have supposed that in the case of cotton fibres, the dyeing material is absorbed into the interior of the fibres by capillary attraction, the absorption taking place by the entrance of the liquid through the broken end of the fibre. This is erroneous, because the author found that in fully ripe cotton, even when the liquid was presented to the sides of a fibre alone, it passed into the interior of the tube, swelling out the portion which had absorbed the moisture, showing that a real transfusion had taken place. This was specially seen when the fibre was mordanted with basic chloride of alumina and dyed in madder. Walter Crum made some interesting experiments in regard to the energy with which this absorbent action operates, and believed it to be due to the smallness of the capillary cavities. In the case of the thin cellulose laminæ which form the thickness of the fibre wall this energy is very great. Crum says, "Whether the mordant be applied to a piece of calico in the fluid state, or made nearly solid with an amylaceous or other thickening substance, it finds no difficulty in traversing the fibre." He further adds, "I have examined threads which have been soaked with a solution of acetate of alumina, altogether fluid, and compared these with other threads which have been

printed with the same solution made into a thick mucilage with gum arabic, and with others again made into a paste with wheat flour so thick that when applied to one side of a piece of bleached calico it would not pass through to the other side, and on examining transverse sections of dyed specimens of these fibres, I found that such of them as had been reached by the mordant were in all cases equally penetrated. The white centre was always due to a want of dye-stuff.

"It is difficult, no doubt, without direct examination to conceive of a capillary power so great, or that a solution rendered so tenacious as to require considerable force to drive it through an opening of an inch in diameter, should be able without any pressure at all to pass into the interior of the fibre, the pores of which cannot be detected by the most powerful microscope."

Penetration by Dialysis.—The investigation of this peculiar property of fluids to diffuse through a membraneous film or septum, formed a new era in our knowledge of the probable nature of the action of dying materials upon the cotton fibre.

Professor Thomas Graham found that solutions of certain bodies pass through membranes with considerable facility, while others pass through very slowly. Most bodies which are of a crystalline character, such as metallic salts, and organic substances, such as sugar, morphia, and oxalic acid, pass through readily, and to these he gave the name of "crystalloids"; while bodies devoid of crystalline power, such as gums, gelatine, albumen, and many soluble oxides, which are in an uncrystallisable condition, such as hydrated soluble silicic acid, soluble sesquioxide of iron, soluble alumina and other similar compounds, pass through very slowly, and were termed by him "colloids." The most

singular part of this discovery was, that of all substances parchment-paper made the most efficient dialysing septum or membrane. The parchment-paper is only matted cotton fibres, which have been modified and strengthened in their structure by the action of strong sulphuric acid, which has caused hydrolysis without destruction of the mechanical texture of the fibre, although it has caused a shrinking up of the laminæ of the tube walls, and by diminishing the distance between them increased the intensity of their capillary action.

This osmotic action, therefore, is related to both diffusion and capillary action, but it bears, so far as is at present ascertained, no exact numerical ratio to either of them, for it depends on the relation between the pores and solid parts of the membrane, upon the nature of the material which forms the dialyser, upon the dimensions of the pores, and upon the temperature and the relative action of the fluid to be dialysed, in relation to that of the dialysing membrane. In a normal cotton fibre there are in the cellulose walls a set of conditions which correspond to all these variables. The rapidity of action which depends upon the osmotic pressure, regulating the transfusion and absorption, is also conditioned by the state of the liquor to be transfused, and the laws which govern it may be stated as follows:—

1. The osmotic pressure is proportional to the concentration of the solution, or to the volume in which a definite mass of the substance is dissolved, supposing always, that the substance is in a perfect state of solution.

2. The pressure for constant volume increases proportionately to the absolute temperature.

3. Quantities of substances in solution, which are in the

ratio of their molecular weights, exert equal pressures at equal temperatures.

Presence of Air in the Fibre.—Another influence is also always at work, which depends on the mechanical structure of the fibre, and that is the occlusion of gas, which fills the pores of the fibre at a higher pressure than that of the atmosphere, since it can absorb many times its own volume of oxygen gas. Some experiments made by the author also seemed to indicate that the fibre exercised a selective action by absorbing out of a mixture of gases a larger quantity of one than another, and this was particularly the case with ammonia. Possibly this arises from the presence of unchanged cell-contents, which are chemically active, and most of which certainly have an acid reaction which would be eminently favourable to the fixation of ammonia.

The presence of air alone, however, must always be taken into account, and the author found that if fibres were thoroughly cleansed from all cell-contents by washing with alcohol and ether and then dyeing in vacuo, the fibre was far more deeply penetrated and the dye was more evenly distributed, and in a much finer state of division.

Method of Association of Dye-Stuff with Fibres.—It will be seen, from what has already been said, that the method of association of the dye-stuff with the fibre depends both on the nature of the dye-stuff and on that of the fibre, and that the ideas which prevail in regard to the matter depend on the view which is taken in reference to the cause of the dyeing operations themselves.

Whatever, however, these views may be, it is well to examine the phenomena themselves and learn what they are, quite independent of any speculations in regard to the cause. With this view, the author some years ago made

a series of observations to determine microscopically the appearance presented by the dye, of different kinds, in association with the cotton fibre, to determine how it was mechanically associated and the characteristics which distinguished the lie of the colouring matter, when the dyeing operation was complete, and it is interesting to compare the results then attained with those presented by more modern examples. At this period most of the dyes in use were derived from the vegetable kingdom, and were the product, except in the case of simple dyes, such as turmeric yellow or annato yellow, of fermentation or oxidation, by means of which the chromogens by the introduction of salt-forming substances are converted into dyes which may be either basic or acid, according to the extent of alteration and the nature of the substitution in the chromophorous groups present in the vegetable extracts Some of these dyeing materials, such as indigo, woad, madder, orchil, catechu, and logwood, have been of the greatest service, and seem destined, except perhaps the two last, to pass away before the more scientific dyes derived by synthesis from coal-tar products, which now yield colours which are even more brilliant and almost as fast as those which were derived from vegetable products. The simple dyes, which have a direct affinity with the substance of the fibre, afford a very good instance in which it is possible to observe the relation of the colouring matter to the fibre, and the method in which it is distributed and fixed.

Action of Simple Dyes.—In the case of turmeric yellow the colouring matter is simply dissolved in hot water, and when the cotton fibre is immersed in the decoction it speedily acquires a bright yellow colour, which is rendered as permanent as the colour will permit by simply drying the yarn. Here the colour is evidently

held in a very feeble state of combination with the solvent water, so feeble that it may almost be considered as only in mechanical suspension in water, along with which it passes into the cellular walls of the fibre, and when the water is dried up, the colouring matter remains entangled in the cell walls which absorbed it, and which have evidently entered into some kind of chemical union with it, since the colouring matter can no longer be separated from it by the application of water, except that a certain amount can be redissolved from the surface, but not the substance of the fibre, showing that a real change has taken place in its nature, since it readily dissolved in water before.

In addition to this, there is an aggregation of the colouring matter not only on the surface, but also within the cellulose walls, as though the fibre possessed the power of concentrating the colour, so that the fibre attracts a larger portion of the colouring matter out of the water into itself, and when taken out is much more coloured than the liquid in which it was immersed. When viewed by reflected light, against a dark ground, which throws up the fibres, they seem to be well and uniformly dyed, the colouring matter being evenly distributed over the whole surface, as may be seen in Fig. 64, which gives the aspect of a number of cotton fibres dyed turmeric yellow and magnified 140 diameters. If, however, they are examined with transmitted light, the colouring matter within the fibre is found to be unevenly distributed and aggregated together in the cavity or lumen of the fibre, as though it was attracted in larger quantity in the interior of the cell than in the porous walls. This may possibly arise from the fact that the pith-like contents of the central cavity are more absorbent than the cellular walls. This can be clearly seen in Fig. 65, which re-

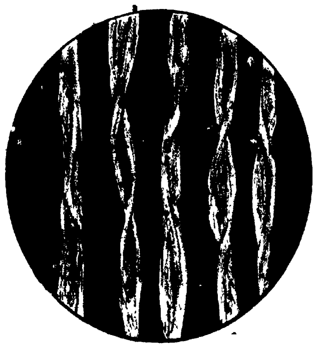

FIG. 64.—Cotton Fibres dyed Turmeric Yellow, viewed with reflected light. × 140 diameters.

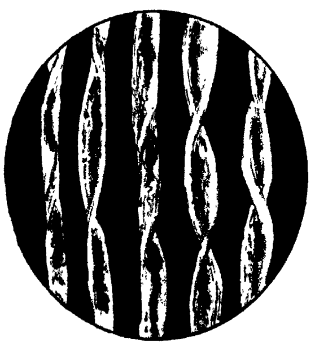

FIG. 65.—Cotton Fibres dyed Turmeric Yellow, viewed with transmitted light. × 140 diameters.

presents fibres magnified 150 diameters, seen with transmitted light against a dark background.

The aggregation of the dye within the fibre seems to be almost directly proportionate, in this case, to the degree of maturity of the fibre, and the thin pellucid unripe fibres scarcely received any stain.

Direct Dyes for Cotton.—These simple dyes have now no place in cotton dyeing, having been almost entirely substituted by what are termed "direct dyes," which will dye cotton full shades without the intervention of any mordant, leaving them comparatively fast, under all ordinary conditions, although they are mostly bleached by prolonged exposure to sunlight. Generally they are prepared by diazotising the bases, and combining the products with amines, or their sulphonic acids, but they may also be mixed products, in which case it is always necessary to select those which are similar in character, and the adjuncts which will be used along with them, such as Glauber salt (sodium sulphate), soda, or soap and sodium phosphate, must be selected according to the predominating components of the mixture.

Congo red, which was the first of these direct dyes, was introduced into practice in 1884, and is the type of a series, all of which are worked as sulphonates of the alkaline metals, sodium, or potassium, or of ammonia, and depend for their action upon the fact that they are tetrazo compounds, and contain the azo group $-N=N-$ twice in the molecule, a basic or an acid dye being obtained, depending on the nature of the change.

$-N=N-$, a chromophorous group.
$C_6H_5-N=N-C_6H_5$, a chromogen.
$C_6H_5-N=N-C_6H_4 . NH_2$, a basic dye.
$C_6H_5-N=N-C_6H_4 . OH$, an acid dye.

The Congo red is produced from benzidine, $NH_2 . C_6H_4 . C_6H_4 . NH_2$, which is itself produced by reducing the corresponding dinitro derivative obtained by the direct nitration of diphenyl, but it is also formed by the intermolecular change of hydrazobenzene, a product of the reduction of azobenzene, $C_6H_5N . NC_6H_5$, which, although highly coloured and insoluble in water, can, as is seen above, by the introduction of the NH_2 and OH groups produce compounds which are either dye-stuffs, when rendered soluble in water, or become dye-stuffs when rendered soluble by conversion into sulphonic acids, and which are the parent substance of many of these important direct dyes. They yield a wide range of violet, orange, red, and other colours. The scarlet red approaches in brightness Turkey red, but is not so fast, although it can both be rendered faster and its brilliancy increased by treatment with Turkey red oil.

They are not, however, as brilliant as the basic dyes or as fast as the adjective, and they are more susceptible to injury in working, caused by the presence of impurities in the raw material which do not affect the adjective dyes.

Many of these dyes are now superseded by those derived from the benzo-purpurin series, which seem to yield more effective results, but they all act as direct dyes to cotton, and have formed one of the most important contributions which chemistry has made to the art of dyeing.

As a rule, it is usual to dye the yellow series in a neutral bath, the blues in a neutral or slightly alkaline bath, and the reds in a strongly alkaline bath.

The benzo-purpurins belong to the same group as the Congo dyes, but whereas the latter become dull by contact with slightly acid fumes, the benzo-purpurin series, which

is produced by combining tetrazoditolyl salts with sulphonic acids of α and β napthylamine, are much more fixed and durable.

It seems probable that the most of these direct dyes enter into union with the cotton fibre in virtue of a real chemical affinity, because their molecular aggregation changes when within, as compared with outside, the fibre. The molecular aggregation also seems to depend upon whether the solvent is acid or alkaline, as Picton found that in the case of Congo red an alkaline solution filtered readily, but the dye would not pass through filtering material in either the neutral or acid state, and suggested that possibly the equalising of the dye by the action of the alkali when dyeing with this series of colours may be due to the same cause, the alkaline solution retarding the action of the dye by preventing precipitation with the acid constituents of the material, and so favouring deeper penetration and more even distribution.

When examining the fibres of cotton dyed with these direct dyes the author was particularly struck by the great penetration of the colouring matter into the interior of the fibre, and the apparently much finer state of division in which the colouring matter appeared to be. Indeed, even when examined by the microscope with the same magnifying power as the simple dyes already mentioned, it was almost impossible to detect any flakiness or discontinuity in the coloured part. This continuity and depth of penetration, apart from any finer division of the molecules of the colouring matter itself, may be due to the much higher temperature which is now used with these direct dyes than was formerly employed. Then the temperature was kept down, but now the boiling point is usually reached. This causes the osmotic pressure, which

increases proportionally to the absolute temperature, to become more active and so to penetrate deeper.

This high temperature also favours the penetration and fineness of division, because, in the first place, all the gummy and resinous material is more easily dissolved and the solution of the dye-stuff is more complete than when a colder dye bath is employed, and also the air is more effectually expanded out of the fibre and the pores opened wider by the increased temperature, and thus resistance to the entrance of the colouring matter diminished.

An examination of cotton fibres dyed with any of these dyes gives a good illustration of these phenomena, since they all appear to behave in regard to evenness of diffusion and penetration in a similar manner, the difference being not of kind but of degree, the molecular aggregation of the colouring matter depending largely upon the degree of maturity and ripeness in the fibres; benzopurpurin red and benzo-indigo blue being selected, so that they can be compared with indigo blue and Turkey red dyed in the usual manner.

Fig. 66 shows a number of cotton fibres dyed benzopurpurin red, when viewed with reflected light against a dark background, in which the distribution of the colouring matter on the surface of the fibre appears fairly even and continuous, and in the thread itself the colour was very perfect and bright. When magnified even four or five hundred diameters, also when seen with reflected light, the appearance was still of a continuous molecular distribution, but when transmitted light was employed and the magnification was increased to 800 diameters, as seen in Fig. 67, the discontinuity then became quite apparent, and the lie of the colouring matter within the fibre in flakes was clearly seen. The penetration of the dye

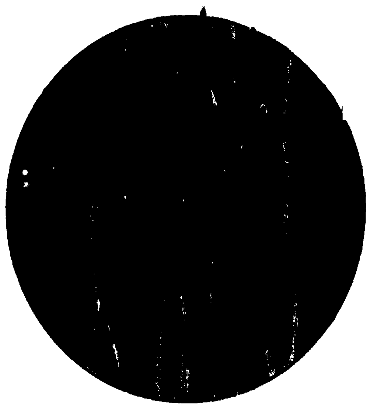

FIG. 66.—Cotton Fibres dyed with Benzo-purpurin Red, viewed with reflected light. × 170 diameters.

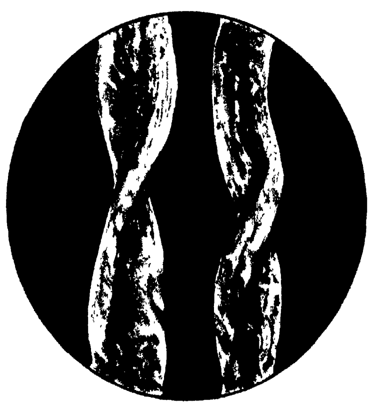

FIG. 67.—Cotton Fibres dyed with Benzo-purpurin Red, viewed with transmitted light. × 800 diameters.

cannot be so distinctly observed by looking at the fibres longitudinally as when seen in section, and Fig. 68 gives a section of three fibres of which one is fully ripe and the others only partially so, and this enables the difference in the appearance of the dyeing in these three instances to be clearly seen. The dye appears to get less deep in shade as the penetration into the substance of the fibre increases. This is what might be expected, because the whole of the dyeing material has to pass through the outer layers of the cellulose deposit on its way inward, and although the dye has in each case passed to the interior of the fibre, there is no aggregation whatever in the lumen itself.

Although the dye in these cross-sections appears evenly distributed, though less in quantity and lighter in shade as it penetrates inward, still, in all the sections, both red and blue, when examined under higher microscopical power, such as 1200 to 1500 diameters, the distribution appeared more and more discontinuous, and could be resolved into separate and distinct flakes of colour, which clearly shows that so far as perfectly even dyeing is concerned, it does not exist even in the smallest areas, either on the surface or within the substance of the fibre.

When examining fibres dyed with the benzo-indigo blue it appears as if the dye was not quite so evenly distributed on the surface of the fibre as in the case of the benzo-purpurin red, as will be seen by looking at Fig. 69, which shows the fibres as seen by reflected light, but when they are magnified more highly and viewed by transmitted light, against a dark background, so as to bring out the colour, the molecular aggregation of the dye and the distribution and penetration appear to be more even than in the case of the red, as will be seen in Fig. 70, which

shows two of the fibres seen by transmitted light and magnified, as in the case of the red fibres, 800 diameters. This is even more distinctly seen in Fig. 71, which illustrates a cross-section of three of these fibres magnified 800 diameters. Both in the red and the blue dyed fibres, when seen in cross-section, it will be noticed that the outer pellicle of the fibre does not seem to have absorbed the dye to the same extent as the layer of cellulose immediately below it. This appearance may, however, be due partly to the reflection of light from the inner surface, as, with the spot lens which was used as a condenser in the microscope, the light was concentrated from all sides in the form of a hollow conical beam.

Action of Dye upon Mercerised Cotton.—It has already been seen that when cotton is mercerised the hydrative action of the alkali causes a change in the mechanical structure of the fibre, which to all appearance is similar to that which occurs in the ripening of the fibre. This is to say, that the cellular layers which are enclosed within the outer pellicle are expanded and thickened, and at the same time rendered more absorbent by becoming more spongy; even the fibres which appear most ribbon-like and with very little thickening in the edges, becoming expanded until, in many cases and in different parts of the fibre, all the creases on the surface are removed and the twist in the fibre largely untwisted, so that this special feature is wanting in many parts of the fibre. The lumen is also almost entirely filled up by the expansion of the cellulose substances. By this means the brightness and lustre is largely increased.

At the same time a chemical change always occurs, one indication of which is a rise in temperature of from 55° F. to 70° F. being noticed in the case of raw cotton, which

FIG. 68.—Cross-Section of Cotton Fibres dyed Benzo-purpurin Red. × 800 diameters.

FIG. 69.—Cotton Fibres dyed Benzo-indigo Blue, viewed by reflected light. × 170 diameters.

appears, moreover, to be different in different qualities of cotton. The alkali also undoubtedly effects a change in the character of the cell-contents, the greatest being of course in those which have been least changed in the process of ripening. The action of the alkali will also, by neutralising any cell-contents which are of an acid nature, prevent their reaction with any of the alkaline contents of the dye-stuff, and so prevent the formation of molecular aggregations. The effect of this action is to increase the absorption of the dye and colour it more deeply, and the result of this is that it is found, with most of the direct dyes, that a smaller quantity of dyeing material is necessary to obtain the same surface shade than when the cotton is unmercerised, because the dye is more evenly distributed.

Mercerised yarn without tension requires on the average about 25 per cent less dye to obtain the same shade than unmercerised cotton.

In Lancashire cotton piece goods are largely treated with caustic soda of 10° to 20° F., with the object of increasing the affinity for colouring matter without increasing the quantity of dye-stuff used, and this treatment is employed specially before dyeing aniline black.

A similar process is used in printing, one side of the cloth being treated with strong caustic soda, and thus much fuller shades are obtained.

It is also interesting to note that cotton dyed with a direct colour becomes considerably darker when mercerised, and when cotton dyed a plain shade is printed in stripes with caustic soda, with the object of producing a crimp, the printed part becomes much darker than the unprinted.

The greater smoothness and lustre on the fibre will be seen illustrated in Fig. 72, which shows a number of cotton fibres dyed with benzaldehyde green magnified 180

diameters, and the deeper colour of the dye is shown in Fig. 73, which represents a section of three of the mercerised fibres magnified 800 times, and which may be compared with the sections of red and blue dyed yarn which are represented in Fig. 68 and Fig. 71. It may be noticed, however, that although the mercerising of yarn produces a more absorbent structure within the fibre, so that the penetration of the direct dyes is more complete, this characteristic produces an opposite effect in those dyes which depend for their tinctorial power upon the formation of coloured precipitates within the meshes of the fibre, or require, as in the case of all the lakes, the formation of a new intercellular surface from which the colour is reflected. In the case, therefore, of mercerised yarns, in addition to the less quantity of dye used, one cause of the greater depth of the colour with adjective dyes appears to be due largely, not to a deeper penetration of the dye, but to a more solid surface deposition. The colouring matter seems to penetrate into the fibre only sufficiently to enable it to key itself into the surface. A close observation of these phenomena also seems to reveal the fact that in the mercerising process the action of the strong alkali attacks the outer pellucid pellicle of the fibre in many parts, and while it also forms a slightly denser layer on the cellulose substance, which forms the secondary deposit beneath it, it enables the dye-stuff to get a firmer hold upon the new surface than if the pellicle had not been removed, and the colouring matter aggregates in denser masses. If in the mercerising process the alkaline action has been too severe, and some classes of cotton stand the action of alkalies better than others, the inner layers may produce, by their expansion, a pressure on the outer pellicle, which has been hardened, and its tensile strength

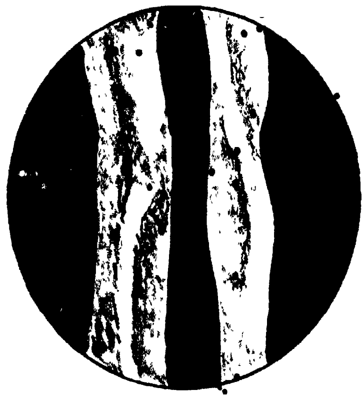

FIG. 70.—Cotton Fibre dyed with Benzo-indigo Blue, viewed by transmitted light. × 800 diameters.

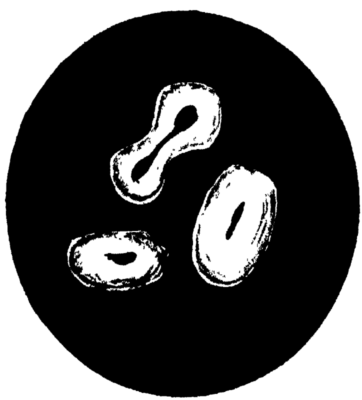

FIG. 71.—Cross-Section of Cotton Fibres dyed with Benzo-indigo Blue. × 800 diameters.

and elasticity weakened by the action of the alkali until it ruptures, and the inner layers of the secondary deposits swell out, somewhat similar to, but in a less degree than, the feeding action of Schweitzer's solution, and the substance of the outer pellicle shrinks up into rings or ligatures round the fibre, and forms curious constrictions.

With mercerised yarns also, in the twisted thread, the shielding action of one thread upon another is much greater than when the yarn is unmercerised, and, as might be anticipated, greater when adjective dyes are employed, as, although the mercerising has rendered the inner contents of the fibre more absorbent to limpid dyes, its finer sponginess, which is more homogeneous and therefore more easily penetrated uniformly by limpid dyes, which, like the direct dyes, are coloured in themselves, offers a greater resistance to those which act by the formation of precipitates, which immediately fill up the pores and prevent any further penetration of the dye. The dye also accumulates in the ridges of the twist between two adjacent fibres, and when the untwisted fibres are examined they present a curious appearance, with the dye-stuff deposited upon them spirally, as seen in Fig. 74, where the dye is entirely topical and does not spread into the fibre. This is still better seen in Fig. 75, where the fibres are in section, and the most part of the interior substance is entirely undyed, as the dye lies entirely on the surface, and only in those parts of the thread which have been unshielded, and so the dye was able to get at the fibre.

Vat Dyes.—Closely allied to these direct dyes there are those which, although the dyeing substance is not coloured in itself, still depends for its action upon the absorptive character of the fibre, and which, as already seen, depends largely upon its mechanical structure, and

although the material when it is presented to the fibre is not a coloured body, it becomes so by the action of feeble oxidising agents, such as the exposure to the ordinary atmosphere. Of these dye-stuffs there are two which stand apart from others, such as indigo ($C_{16}H_{10}N_2O_2$) and indophenyl blue, the typical formula for which is $OC_6H_4NC_6H_4OH$. Both these substances are in themselves coloured, and both are insoluble in water. In each case the colour depends upon the relation of the oxygen and nitrogen groups within the molecule, and when this relationship is disturbed by the introduction of hydrogen into the molecular grouping in such a way that the intimate relationship of the original oxygen and nitrogen groupings is disturbed, leuco-compounds, as they are termed, are formed. In the case of indigo two or more molecules of hydrogen are introduced into the chain, and the indigo formula, which is $C_{16}H_{10}N_2O_2$, is changed into $C_{16}H_{12}N_2O_2$, which is known as white indigo. This is soluble in water, but when oxygen, which had been removed by the reducing agent, is restored, the colouring matter is again formed, and as this is insoluble it is precipitated within the meshes of the fibrous substance, and so permanently retained. These leuco-compounds are produced in an alkaline bath or vat in which the indigo, in a very fine state of division, and in the presence of lime-water and hyposulphurous acid, ferrous sulphate, or zinc oxide, is decolourised and rendered soluble. The same process is used to form the leuco-compounds when artificial in place of natural indigo is used, but in the former case the indigo itself is in a more pure form than in the natural indigo, but the impurities in the latter seem to give a bloom to the deeper shades, which is absent when artificial indigo is used. This arises from the presence of certain undefined red and other colouring matters. On this

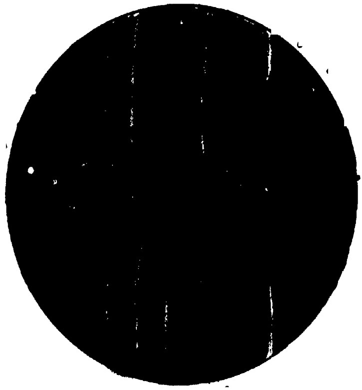

FIG. 72.—Mercerised Cotton Fibres dyed Benzaldehyde Green. × 180 diameters.

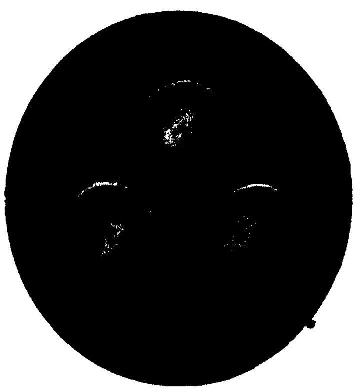

FIG. 73.—Section of Mercerised Cotton dyed Benzaldehyde Green, viewed by transmitted light. × 800 diameters.

point there is a difference of opinion, but in skilled hands the same shades or even brighter can now be obtained by the use of synthetic indigo.

The material to be dyed is worked in this vat either in the cold or hot state, as may be deemed most advisable, and the soluble leuco-compound is absorbed into the fibre. The action which the fibre exerts upon the solution of indigo seems to be more than the mere interpenetration of the cellular tissue of the fibre, as though the dialysing action tends to accumulate the soluble indigo within the cell-walls in quantity almost proportionate to the time during which it is acting, so that if there is sufficient quantity of the cotton it will extract the whole of the indigo from the solution.

In this respect this cumulative action is similar to that of the fibre upon the turmeric solution, except that the white or soluble indigo is not coloured and visible to the eye, although when dried, before exposure to oxygen, it seems to be attached to the fibre in its yellow insoluble state.

The stability of these colours formed by the oxidation of leuco-compounds has led during the past few years to the introduction, for cotton dyeing, of a whole range of vat-dyed colours known as the Indanthrine series. The chief characteristic of this class of dyes is their great fastness to light, washing, alkalies, acids, and even in several cases chlorine. The method of using these dyes is similar to that employed when indigo is used. They are reduced in a vat by means of hydrosulphite in the presence of caustic alkali, yielding clear solutions, which often differ in colour from the original colouring matter and give up leuco-compounds to the cotton fibre. When oxidised the indanthrine colour remains fixed in the fibre. The temperature of the bath is usually 140° F., and the colour

is often heightened by dipping in a hot soap bath. The range of these colours is rapidly extending, and they now yield blues, greens, browns, yellows and reds in many shades. They are placed on the market under various names, such as algol, dianthrine, thio-indigo-red, etc., and while their behaviour and appearance under the microscope are, in regard to the cotton fibre, very similar to indigo, in the lighter shades especially, the diffusion seems to be greater and the molecular aggregation less massive and solid, and the internal reflection of the light greater.

Power of Concentration in Fibre.—This power which cotton seems to possess to concentrate solutions within itself, seems analogous to that which it has of occluding ammonia and oxygen within its pores, and the power to absorb the latter is enormously increased when the fibre is impregnated with the reduced indigo, because there is also an affinity between the indigo with which the fibre is saturated and the oxygen of the air.

When the oxidation has taken place and the colour restored the cloudy deposit of indigo blue is clearly seen, irregularly distributed through the meshes of the fibre, in many cases penetrating into the central cavity or lumen, and forming dark and almost black masses where it is accumulated in the largest quantities. This will be clearly seen in Fig. 76, which shows a number of fibres dyed indigo blue, seen by transmitted light and magnified 230 diameters. In some of the fibres which are not fully ripe the dye has only partially taken effect, and the much less even distribution of the dye can easily be seen if compared with that obtained by means of the direct dyed artificial blue shown in Fig. 69. A section of three fibres seen under the microscope and magnified 700 diameters exhibits the uneven distribution of the dye within the fibrous walls

FIG. 74.—Mercerised Cotton Fibres, untwisted from Thread, dyed Crimson Lake. × 200 diameters.

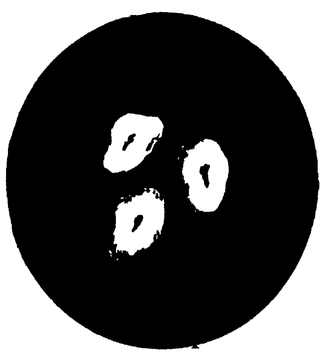

FIG. 75.—Section of Mercerised Cotton Fibres dyed Crimson Lake. × 300 diameters.

in a still more striking manner, as will be seen in Fig. 77. Although the molecular aggregation is great, so that the colour is clustered together in masses, still the fine state of division of the colouring matter and its non-crystalline character render it less liable to disturbance from the flexure of the fibres than many other dyes, and its perfect insolubility in water permits a considerable amount of surface coloration, which, when viewed by reflected light, causes the fibre to appear much more evenly dyed than when transmitted light is employed. Indeed, this surface coloration is always more or less visible in all fibres which are dyed by the formation of insoluble colouring matter, or which are not subjected to severe after treatment, so as to remove all dye which is only mechanically attached, and this usually masks many of the defects which would otherwise arise from imperfect formation within the fibres.

The colouring matter accumulates in the creases and on the wrinkled and broken surface of the collapsed tubes, or in the ridges and furrows on the surface of the thread by the hollows of the twisted fibres, and thus forms a coloured reflecting surface, to which the solid and even appearance of this dye is largely due.

The foregoing examples may be taken as representatives of the substantive dyes, which require no previous treatment of the fibres except simple washing in hot water or a slightly alkaline solution, which is necessary to remove the fats and waxes which would otherwise interfere with the absorption of the dye-stuff by the fibre.

Topping of Direct Dyes.—It has already been noticed that, to a certain degree, all direct dyes on cotton are subject to removal by washing, and that the surface coloration is apt to run when woven in connection with,

and juxtaposition to, white threads, such as bleached yarns, and it has been found that this defect can be remedied and the dye rendered not only faster to washing but also to light by topping them with basic colours, which in addition also heighten their colour. The basic colours are coloured salts produced by union of organic bases, all of which have an artificial origin, with acid salts. These salts are mostly simple chlorides, but double salts are also used, and acetates, oxalates, sulphates, or nitrates. Where these in a state of solution are brought in contact with hydroxides or carbonates of the alkaline earths the colour bases are thrown down in the free state, and are mostly insoluble in water. When used to top the direct dyes these coloured lakes not only form a protective covering to them, but also what is virtually a new surface within the fibre, which increases the depth of colour radiation, and is probably the cause of the heightening of the direct colour.

Another method of fixing these direct dyes can also be employed, because a large number of them are capable of being diazotised in the fibre, and forming azo-compounds with the phenols, amines, etc., and these new compounds are insoluble and fast to the ordinary process of washing. This process seems to be capable of considerable extension.

Action of the Fibre on Mineral Dyes.—Amongst adjective dyes which require a previous treatment of the fibre with another reagent, so as to enable the colour to be formed and fixed, may be classed the mineral dyes, such as Prussian blue and chrome yellow, although the former perhaps should not be classed as such, since the prussiates upon which its colour depends are organic compounds, the iron salt acting as the mordant, and the Prussian blue may be represented by the formula FeC_6N_6.

Both have been largely replaced by artificial dyes, and

FIG. 76.—Cotton Fibres dyed Indigo Blue. × 230 diameters.

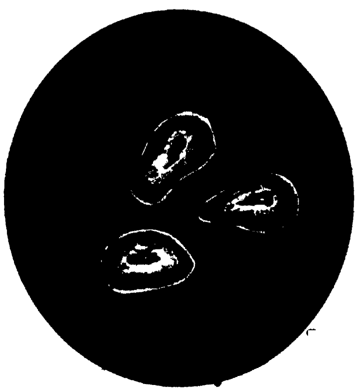

FIG. 77.—Section of Cotton Fibres dyed Indigo Blue. × 700 diameters.

will probably be ultimately entirely superseded, and indeed the chromates and allied manganates are probably those which will survive the longest.

In this class of dyes probably the fibre substance itself has a more passive condition than in any other form of dyeing. Here true chemical precipitates are formed within the substance of the fibre, and the reaction which produces them is exactly the same as that which occurs in the test-tubes in the laboratory when testing for iron or lead. The art of dyeing in these cases is simply the preparation of the fibre, so that it will receive in the best possible manner and to the fullest extent the solution of the substance which is afterwards to be precipitated. The passive nature of the fibre during this reaction between the constituents of the coloured salts is shown by the fact that in some cases, such as chromate of lead ($2Pb, CrO_4$), the colouring matter often assumes a crystalline character within the fibre, which shows that the molecules, or at any rate a large number of them, are not united by any chemical bond to the cellulose, but are free to exercise their crystalline affinities in exactly the same way as if they were within a neutral vessel.

This is often specially noticeable in the case of chrome yellow, where the chromate of lead is easily distinguished by the peculiar form of the crystals, the primary form being an oblique rhombic prism, which generally occurs with truncation of the basal and lateral edges. These form a pretty object when viewed by polarised light, which is very efficacious when employed to detect the presence of crystalline structure. These crystals seem, in some cases, to shoot through the walls of the cell membrane, possibly in lines of fracture of the tube walls, and they not unfrequently seem to cause a weakness in the fibre by the

sharp angles of the crystals cutting through the thin cellular walls when the fibre is subjected to strain.

This probably occurs in other colours, where the resulting dyes are easily crystallisable salts, and in some cases this may account for the weakening action of certain dyes, just as in other cases, when the dyeing material feeds the fibre and expands the cellular layers, the act of dyeing confers additional strength.

This crystalline character is, however, entirely wanting in many cases, and the tendency to produce crystals may depend on the peculiar method which is employed to produce the colour, which may vary slightly at different times, or with the amount of colouring matter which has been introduced into the fibre, or even the length of time which has been employed to dry it.

It may not be uninteresting to note that chromate of lead seems very largely to coat the surface of the fibre, as well as to pass into the interior. It accumulates in the twists and creases of the cotton filaments composing the thread in a fine crystalline powder, and when viewed with reflected light gives a yellow, glistening, velvety appearance. The tendency to surface coating is manifest more or less in all colours, the dyeing materials having their attachment to the spaces between the individual hairs forming the thread and in the spiral creases caused by the twist, which has been put into the yarn in the process of spinning and doubling. This surface colouring undoubtedly serves the purpose of masking many of the defects which would otherwise be visible, arising from the imperfect dyeing of the individual fibres, but its ready removal in any after finishing process to which the yarn or goods may have to be subjected renders it also a source of danger, as when removed it will reveal irregularities in colour

which were not visible before being subjected to these processes.

Mixed Goods and Cross-Dyeing.—Those who are acquainted with the union trade in which cotton and wool are mixed together, know how frequently defects arise in cross-dyed goods, caused by the stripping of the warps in the clearing process necessary for the dyeing of the weft, and unless the warp dye is thoroughly fixed upon the fibre streaky places are sure to appear, especially in cases where a large portion of the warp as well as of the weft appears upon the surface.

Unfortunately chemical science has not yet provided direct dyes, which in the same dye bath and at the same temperature dye any shade equally well and the same depth of shade both cotton and wool. The fact, also, that cotton is dyed best in a neutral or alkaline bath, and wool in an acid bath, except in some few cases, appears to present an almost impassable barrier to success, but it opens up a wide field for investigation, and some such processes as the animalising of cotton by some easy method may possibly some day solve the difficulty.

In relation to the mineral dyes, the author found that in some cases it was possible to remove the cellulose and leave the dyes with which it was associated unchanged, which shows that in such cases there is only a mechanical association between the fibre and the dye.

Notwithstanding this, however, it seems probable that there is a chemical affinity between the impure cellulose, as it always occurs in the cotton fibre, and the first solutions in which it is immersed in order to produce these mineral dyes. Many of these unchanged cell-contents, in the half-ripe fibres, where the protoplasm is charged with tannin-like bodies, act in fact as mordants, and so fix some of the colour.

The author made a series of experiments to determine these points, and found that when cotton fibre was steeped in acetate of lead, which is the first process in the dyeing of amber, or nitrate of iron, which is the first stage in dyeing Prussian blue, that he could never by any process which did not entirely destroy the very nature of the fibre remove all traces of these bases, which seemed to indicate that more than a mere mechanical absorption had taken place between these salts and the semi-cellulose constituents of the fibre walls, and that although the cellulose itself may play no part in the reaction which occurs when the chromate of lead or Prussian blue is precipitated within the meshes of the fibre walls, still, there is in some way a reaction of the bases upon the cellulose, which tends to give greater fixity to the colouring matter. As a consequence of this partial chemical action, there may also be within the fibre walls a larger quantity of the dye than there would have been as the result of the artificial mordant alone, and thus the fixing of the dye-stuff may be chemico-mechanical.

Some years ago, when in the Bradford trade very fine single and twofold cotton yarns were being used, all of which were made from Egyptian cotton, and the run was principally upon light and delicate shades, the author was called in to more than one arbitration where individual fibres and masses of fibre had turned black or dark shades in all those colours where salts of iron were used in the dyeing process, and from the appearance of the dark colouring matter in the cell-walls of the individual fibres he was convinced that it arose from the presence of a tannin-like body which was present in the juices of the growing fibre, and which, from want of sun during the growing season, had never changed into more neutral compounds, and therefore entered into combination with

the iron, producing a kind of ink, with the consequent result of causing serious defects in the goods, which could not be removed out of the yarn by the ordinary method of washing or cleaning the warps. This defect appeared not in one spinning alone but in several, and the warps were dyed by different dyers. The next season, with the same shades and goods, this defect did not appear, nor had it done so in previous years, although exactly the same method of dyeing had been employed.

Relation of Cotton Fibre to Mordant Dyes.—In dyeing fibres with dyes which have either very little or no affinity whatever for the substance of the fibre, as previously stated, it is necessary to use another substance with which it has affinity as an intermediary agent. In the case of the mineral colours, it has been seen that the reaction which produces the colour is quite independent of the fibre substance, which only acts as a containing vessel. This is not quite the case where mordants are used, as in most cases the fibre does itself enter into the reaction, either mechanically by dialysis or chemically in virtue of selective affinity.

In dyeing with mordants there are really three operations necessary.

1. The impregnation of the fibre with the mordant.

2. The fixing of the mordant within the fibre, so that it will be permanently retained.

3. The impregnation of the mordanted fibre with the dye-stuff.

The substances used as mordants must be soluble, or they could not enter the substance of the fibre, and also such that when they have undergone a process of fixing within the fibre they will combine with the dye, either being coloured by the dye-stuff or forming a coloured body with it.

The mordants usually employed are salts of aluminium, chromium, iron, tin, and alum salts, which are double sulphates containing a monoatomic and triatomic metal, acetates and thiocyanates, which, when treated with water or steam, yield an insoluble basic salt or metallic hydroxide, which remains fixed within the fibre.

In this manner alumina has a special interest in connection with the cotton fibre, because it not only possesses the peculiar property when in its hydrated condition of throwing down, and not only heightening the brilliancy of many vegetable and animal colouring matters, but also of being separated from its various compounds by the dialytic action of the fibre alone, and thus retaining it within the substance of the fibre in an insoluble condition. Upon this action depends the process of dyeing Turkey red, one of the most stable of all colours, and for which cotton is particularly suited.

Formation of Lakes.—If an aqueous solution of alum ($K,Al(SO_4)_2$) be taken, and an alkali added, there falls to the bottom of the containing vessel a copious white, gelatinous-looking precipitate, which is hydrate of alumina ($Al_2O_3,2H_2O$). If the alum solution contains colouring matter, such as cochineal or alizarine red, the precipitate of hydrate of alumina carries this colouring matter down with it, and leaves the solution almost colourless. It does not seem that there is a chemical combination between the alumina and the colouring matter, but only as if the colloidal precipitate of the gelatinous hydrate entangled the finely divided colouring matter in its mass, in the same way that coagulated albumen in blood or the white of eggs will clear the brown colouring matter out of concentrated solutions of sugar in the process of manufacture.

When cotton fibres are steeped in aqueous solutions of alum, and then, after drying, placed in pure water, a precipitate of the hydrate of alumina is left within the substance of the fibre without the presence of an alkali. This most probably arises from the fact that the crystalloid portion of the alum diffuses through the outer pellicle, acting as a dialyser into the surrounding water, while the colloid has no such power, or only to a feeble extent, and so remains in an insoluble condition behind. Other metallic oxides participate with alumina in this property to a varying extent.

Turkey Red.—Two of these alumina lakes, produced by mordanting with monochloride of alumina and dyed with madder and oxychloride of iron dyed with garancine, were exhaustively treated by Walter Crum, in his paper already mentioned, "On the manner in which Cotton unites with Colouring Matter."

In speaking of the former Crum says: "Many of these fibres seem as if a thin film of alumina had originally been deposited within them over their whole length and breadth, and in all of them there is evidence of the deposit having shrunk to a great extent in both directions in the process of drying. It is remarkable that the alumina should adhere so slightly to the membrane which contains it as thus to shift without difficulty from one part to another in the act of shrinking. The same remark applies to the clots found in the centre of full-grown cotton, whether the mordant of iron or alumina be applied from an acetic solution, or, as in the case before us, a basic solution."

These appearances will be distinctly seen in Fig. 78, which represents a number of these fibres magnified 240 diameters, and which were sketched from the original

slides prepared by Crum, and which were for some time in the possession of the author.

In the kempy fibre many parts are quite uncoloured by the dye, while in the unripe pellucid fibre the colouring matter is confined to a thin layer which, by the act of shrinking, has become separated into distinct flakes, detached from each other and distributed irregularly. The fully dyed fibre shows the accumulation of the colouring matter within the cellulose walls.

Fig. 79, also sketched from Crum's sections and magnified 250 diameters, shows the distribution of the colouring matter in the lateral direction, some of the fibres being hardly coloured at all, while others have the dye collected in the form of a mass or clot within the tube. The diffusion and distribution of the dye within the cellulose layers is also distinctly seen, and in some instances reveals a distinct appearance of lamination.

One of the fully ripe fibres shows the appearance of an uncoloured outer pellicle, while the interior is well dyed through to the centre. By previous bleaching of this fibre the quantity of alumina which it can receive is much diminished, but enough is admitted to enable it to form a beautiful microscopic object.

In all cases the cell remains beautifully colourless and crystalline, enclosing its flakes of carmine; and the variety in the distribution of these flakes is infinite.

Effect of Bleaching on Mordants.—The effect of bleaching in diminishing the power of cotton to receive mordants is to be attributed to the boiling in weak solutions of quicklime and carbonate of soda to which the cotton is subjected, and not to hypochlorite of lime, which is very sparingly used in the process of bleaching, nor to sulphuric acid, which does not affect the mordanting.

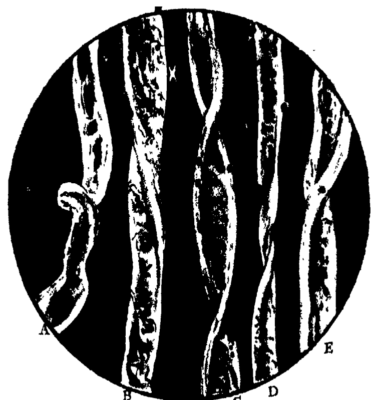

FIG. 78.—Cotton Fibres dyed with Lake of Alumina and Madder × 240 diameters.

A. Kempy fibre.
B. Unripe, pellucid fibre.
C. Fully ripe dyed fibre.
D and E. Partially dyed fibres.

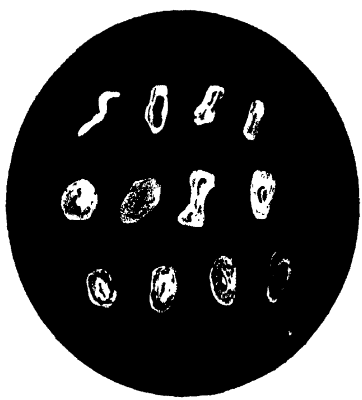

FIG. 79.—Sections of Cotton Fibres dyed with Lake of Alumina and Madder, exhibiting various degrees of Colour acquired by the Fibre. × 250 diameters.

Hypochlorites in excess open the pores and laminæ of ripe cotton fibres, and by enabling them to admit more of the mordant greatly increase the intensity of the dye.

The comparison of the fibres shown in these two last figures with those previously shown in this chapter, which exhibit the appearance, when seen by reflected and transmitted light and also in section, of fibres dyed with direct dyes, is very instructive, and especially the diffusion and penetration of the dye in the sections.

The process of dyeing Turkey red is essentially the formation within the fibre of a new and more receptive and reflective surface, which is an aluminous base dyed with an alizarine red, and it seems also that for its perfect production fatty acids are essential, which are usually supplied in the form of olive or castor oil which has been treated with sulphuric acid until the product is entirely soluble in water. The excess of acid is then removed by washing in a solution of sodium chloride, and the residual acid neutralised with soda or ammonia. Acid soaps made by treating a dissolved soap with just sufficient acid to prevent separation of the fatty acids may also be used in place of the special Turkey red oil.

The fibre to be dyed is impregnated with the prepared oil and then dried so as to fix it within the fibre before the cotton is immersed in the aluminium salt.

Stork and Coninck (*Bull. Soc. Ind. de Rouen*, 1887, p. 144) assert that the action of light is an important factor in the correct formation of these fatty acids, and hence in the old process of Turkey red dyeing the hanks of yarn were always sun-dried. The active principle in all these soluble oils appears to be ricinoleic acid, which is an hydroxy-oleic acid ($C_{17}H_{32}(OH)CO_2H$).

Artificial Surfaces.—The possible production of an

artificial surface within the meshes of the fibre is an important matter, and deserves serious consideration, because, if a method can be found by means of which this can be accomplished at such a price as will pay commercially, and in such a manner that it will be continuous and not disruptive, and will not shrink during the process of drying, it may be possible to produce more brilliant and permanent colours than have yet been attained.

To a certain extent this is being done in cloth when dyed in the piece, although not by producing a new surface within the fibre, but by forming a new surface on the combined fibres as associated and in situ in the woven piece by the hydrolysing action of alkaline solutions, similar to mercerising, which produces a surface of hydrated cellulose, which is much more receptive to dyes than the ordinary surface. It need not be pointed out that in all cases the cotton must be thoroughly cleansed from all size and other foreign material.

In the same way, by the production of a viscose surface upon the cloth, which gives each fibre a smoother and more lustrous surface, the regularity in the distribution of the colouring matter may be greatly increased, and at the same time a much stronger and firmer fabric produced.

Natural Colour in Cotton.—Mention must also be made of the occurrence of natural colouring matter in cotton, which in some cases is sufficiently marked to enable the natural fibre to be used without dyeing in the obtaining of écru effects, and the depth of colour is materially increased by exposure to diffuse light, while it is often bleached and becomes lighter when exposed to direct sunlight when the cotton is dry. It is also deepened by steaming, as will be known by all doublers who steam

the single yarn, to take out the curl before being used either on the twiners or frames.

In some cases, where the darker shade is disadvantageous, the cotton cops are soaked in water and left to drain, without the use of steam, immediately before doubling, and where, as in the case of wet doubling, which is usually employed, no disadvantage accrues, as the yarn simply takes up less moisture from the troughs or damp cloths, and is equally dry when the process is finished.

This colouring matter, although it is found in Brazilian and South American cottons to a small extent, and more in some years than in others, is most noticeable in Egyptian cotton, specially in the indigenous variety, where the endochrome gives a dark reddish-brown or golden colour to the fibre. This is probably a reversion, as it has already been pointed out that all wild cottons have the fibre more or less coloured by a reddish endochrome, which, however, usually disappears under cultivation.

This colouring matter is not evenly distributed through the fibre, but occurs most frequently towards the upper end, where it has been most exposed to the action of light, and also is unevenly distributed in the boll.

This deepening of shade, when the fibre is ripening, is the reverse of the bleaching action when it is plucked and the vital activity of the cell protoplasm has ceased, but at the end of the fibres, where they taper off, and the cell cavity is entirely filled up and the point becomes solid, the bleaching action occurs just the same as in the dry cotton.

This colouring matter, when examined under the microscope, is found not only in the interior of the lumen, where, however, it is usually most distinct, but is also associated with the cellulose layers which form the

thickness of the fibre walls. With moderate powers this colouring matter, which is evidently organic because it does not react with any reagent, in the majority of cases seems evenly distributed through the parts which are coloured, although these parts or regions of the fibre are themselves unevenly distributed. In a few cases the author was able to discover evidence of discontinuity in some fibres, and specially in the colouring matter in the pith of the fibre, where the cell-contents were most active. It is often necessary to bleach this colouring matter out of the fibres before they can be made sufficiently colourless to receive the lighter shades of fancy colours.

When Egyptian and American yarns are placed side by side this difference of colour is very striking, and usually forms a ready means of distinguishing them.

Where the cotton fibre has been perfectly purified from the various materials which are associated with it, such as the waxes and oils, and unchanged cell-contents, it becomes very receptive to any foreign matter with which it may come into contact, and if perfect dyeing is to be attained, it is necessary to exercise every care, so that nothing will interfere with the free action of the outer pellicle and containing layers as dialysers.

Extraneous Hindrances to Dyeing.—While the structure of the fibres themselves, and their chemical constituents, often interfere with the dyeing of cotton, there are undoubtedly many other imperfections in manufactured goods which are not the result of these causes, and it may not be uninteresting to notice some points where difficulties have arisen.

The author was on one occasion called in to look at some pieces which had taken the dye very irregularly. The pieces had been woven in the grey and cross-dyed after-

wards. For many inches in some places in particular threads, and sometimes in more than one thread, the colour seemed hardly to have taken in the warp.

The dyer and finisher were of opinion that it was either mixed cotton, such as Egyptian and American, or that something was associated with the cotton, as it was quite impossible to get it even. When the threads were examined under the microscope small particles or masses of a waxy substance were found on the surface of the defective fibres, and it was then discovered that, in consequence of the want of strength in the warp, which was a twofold with very slack twist, a wax roller had been used, over which the warp passed, so as to give greater tensile strength. The same warps when woven without the roller took the dye perfectly. Cotton-seed oil, which is derived from the seed being broken up in the process of manufacture, and which is present in more or less degree in all uncombed yarns, frequently becomes attached to the surface and soaks into the thread. The oil which exudes from these portions of seed penetrates into the adjacent fibres, and possesses great diffusive power, especially in the new crop cotton, where the seed oil is uninspissated and more limpid than later on. This diffusive power is greatly aggravated when subjected to heat, such as the hot rollers in finishing, which frequently causes the oil to extend to a considerable distance all round the bit of seed, even impregnating the adjacent threads. In Egyptian cotton and other varieties where there is at the pointed end of the seed a growth of short, thick, and solid fibres, which cannot be removed by ginning, and which themselves exude a gum, as will be seen by reference to Fig. 41, attached to the sides of the fibres, these are frequently mixed with the longer fibres, and are a cause of great annoyance. The dye

in these fibres is only deposited on the surface, as the seed oil within prevents the dye penetrating inward, and in the finishing process, when the piece is calendered or hot-pressed, the surface of these small fuzzy fibres is disturbed, and the portion of undyed fibre beneath presents a marked contrast to the more completely dyed thread.

Whenever light shades are to be dyed it is important, with carded Egyptian yarn, that great care should be used in the clearing of the yarn, so as to completely remove all traces of these broken seeds or short adherent fibres from the thread, or they are sure to cause imperfections. The author remembers seeing a piece of cloth which was spotted all over the light surface with more or less dark spots, and when examined under the microscope he found a small speck of seed in the centre of each, out of which a drp of oil had been squeezed by the pressure of the hot finishing rollers.

On this account the importance of the ginning process cannot be over-estimated, because unless the separation of the fibre from the seed is as complete as possible, any portions of seed, either by themselves or associated with the short fuzzy hairs, are carried along with the lint and are broken up in the scutching or carding into pieces too small to be removed, except by combing, and those pass forward into the yarn.

On another occasion when small spots or defects appeared on the surface of a cloth, it was found that cinder dust from a mortar-grinding mill was blown in at open windows, and that it settled and got fixed in the meshes of the cloth. One of these small cinders formed the nucleus of each defect, and could be clearly seen under the microscope, and the iron and other salts dissolved from the cinder, when wet and exposed to the air, caused the dark spots and stains forming the defect.

Purity in Size.—In single warps, which require sizing in order to increase the strength in weaving, the composition of the sizing material is an important matter, and especially when the weft has to be dyed after the piece is woven, for although, in the union trade, where the weft is worsted or woollen, heavy sizing in the goods does not pertain so much as in all cotton goods, still it does exist to some extent. The size must always be perfectly removed from the warp before the weft is dyed, and it not unfrequently happens that where such a salt as zinc chloride has been used as an ingredient in the size, this can never be entirely removed, and will act as a mordant. The author has frequently seen coloured stains produced by the action of foreign substances upon the material of the size and then fixed into the substance of the fibre itself, as well as the production of mildew, which arises from microscopic fungus growths which feed upon the substance of the size.

Importance of Clean Apparatus.—The utmost importance attaches to the perfect cleansing of the various vessels and machines used in dyeing and finishing, before being used for different dyes and different classes of goods, and undoubtedly many mysterious imperfections may be traced to the neglect of these precautions and to a variation in the quality of the water used in the process. Even volatile substances which may be conveyed in the steam used for dyeing purposes, and which may arise from impurities in the water pumped into the boiler or from the use of anti-crustation boiler compositions, have been known to cause trouble in dyeing, bleaching, and finishing. The author's attention was called, some time ago, to some pieces where the surface was strangely marked with uneven shades in the finished goods, which defects were not visible till the last process was complete. This process

consisted in subjecting the goods to hydraulic pressure between hot iron plates with mill-boards between the folds of the cloth.[1] These boards had been used before with a cloth which was either imperfectly cleared, after dyeing, or some portion of the dye had been taken into the surface of the mill-board and transferred to the face of the new cloth, so as to discharge, under the action of the heat, a portion of the dye, and thus produce the mottled appearance.

When new boards were substituted the same goods came up quite perfect, although nothing was present on the surface of the old boards in sufficient quantity to be detected by the eye, or even by the ordinary processes of chemical analysis. Even the presence of volatile substances, such as creasote, carbolic acid, ammonia, or chlorine in the atmosphere, has been known to affect the dyeing of yarns which had been stored in the bundle or warp in the same room in which these materials were present. This result might almost be anticipated, from the great power which cotton possesses of absorbing gases.

Variation arising from Different Cottons.—The variation in the colour of cotton from year to year, or even of different mixings, when sufficient care has not been taken to match for colour, often affects the evenness of the dyeing. This is usually, however, visible in the grey, and can then be removed by bleaching before dyeing. Apart from this, cottons of different qualities and varieties vary in their power to receive full and even colours, and this also extends to the same kind of cotton grown in different years, and which depends upon the climatic conditions which prevail from year to year.

Effects of Stripping in Cross-Dyeing.—There is always more difficulty in preventing defects and in getting an even surface in dyeing when goods are cross-dyed,

because the process of dyeing the weft, and especially in union goods, has a marked effect upon the colour of the warp, and it is not possible to allow completely for this in the original dyeing of the warp. The author recently saw a number of samples of the fastest colours which could be dyed upon cotton, and which had been passed along with some pieces through the cross-dyeing process, and was much struck with the appearance as compared with the original samples.

The suitability of various dyes to go together, so as to enable cross-dyeing to be carried out successfully, without injury to the warp, with various fibres, such as wool, silk, cotton ramie, and other bast fibres, is a matter of very great importance, and specially since the introduction of direct dyes, and it may be interesting to note that in the research laboratory of one of the largest dyeing associations in this country very extensive researches are now being made in this direction, and yielding important results.

Dyeing and Cotton in Different Years.—It would be impossible to mention all the causes which lead to imperfection in dyeing, which, quite apart from the dye-stuff itself and its manipulation, interfere with the proper reception of the dye by the fibre, and it can only be possible to attain perfection in this department by careful detail in every particular condition and operation upon which it depends. It has already been noticed that variation occurs in the cotton grown in different years, arising from the condition of the fibre mechanically and in regard to structure, as a consequence of more or less maturity in the development of the average fibres, and this must be taken into account at the beginning of each season by the dyer in the same way that the spinner has to vary his mixings, by a fresh selection of standard samples, if he is

to keep the quality of the yarn perfectly regular. The advance which chemical science has made during the last two decades, and especially in regard to the substitution of artificial for natural dyes, which enables a far greater command to be obtained over the products than formerly, gives promise of still further advance.

Even yet the threshold of our knowledge respecting the means which may be ultimately employed seems to be hardly passed, and there is a wide field open for research into a means of increasing the strength and smoothness of the fibres of the various raw materials, so as to render them better fitted for textile purposes. This has already been accomplished to a certain extent as a result of the changes which cellulose undergoes under the action of reagents, and the ease with which its molecular constitution may be restored to its original condition.

Many of the forecasts which were made by the author in his work on the cotton fibre which was written twenty-five years ago, and especially those in regard to the importance of the mercerising process and the production of direct dyes, have already been accomplished, but the remarks with which the volume was concluded are as true to-day as they were then, and no apology is therefore needed for their insertion here.

A careful examination of almost any dyed yarn reveals how superficial after all are the best dyeing processes, the untwisted fibres exhibiting in many places a complete want of colour. Even in Turkey red, where the process is most severe and prolonged, the dyeing material is to a marked extent close to the surface, and even a very slight curl in the yarn prevents the thread from receiving the dye in many parts.

This is a very important matter, since it shows how